Introduction to the DRD1 Work Packages

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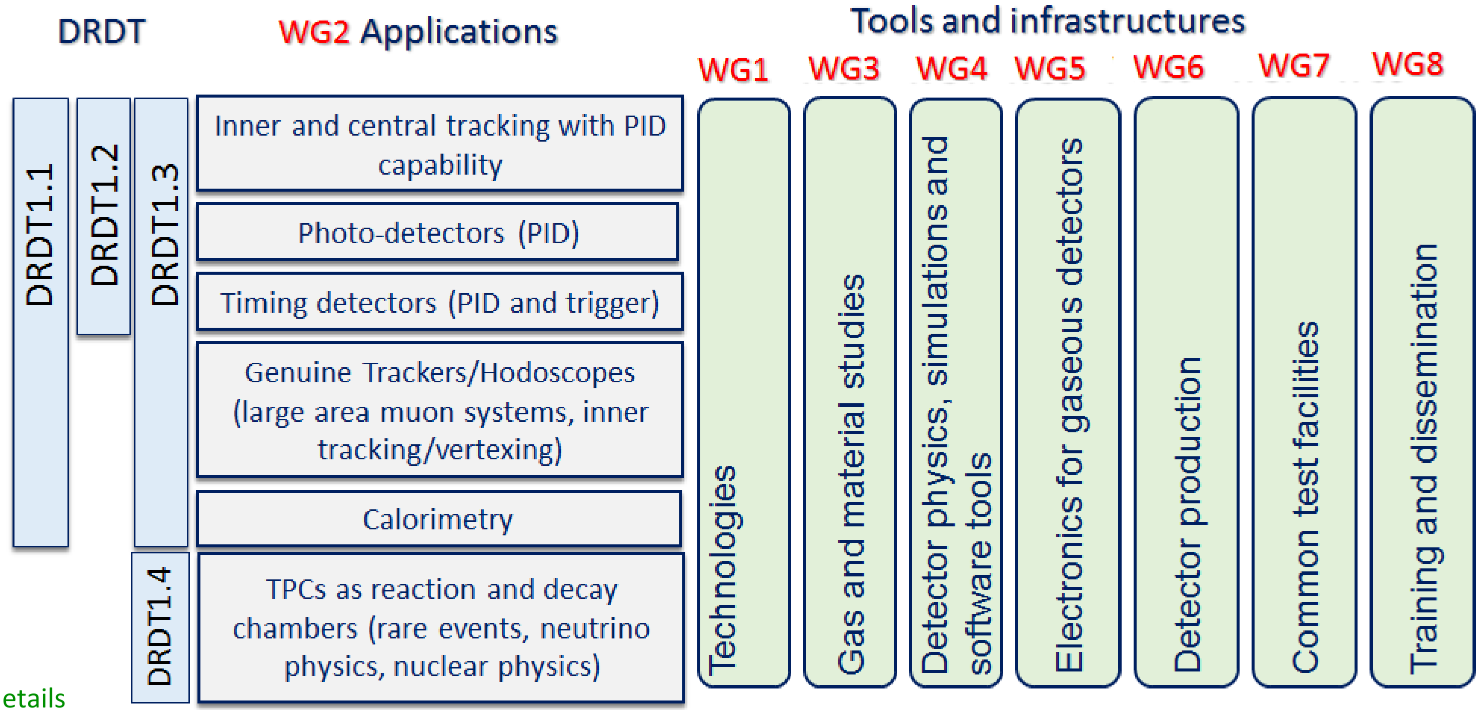
(on behalf of DRD1 WG2 conveners and WP coordinators)

RD51 Collaboration Meeting
19 June 2023

DRD1 structure

- Structure in Working Groups, forum for scientific discussions, coordinated by conveners:
  - aligned with the scientific program of the ECFA roadmap through the applications related to future facilities challenges, outlined by R&D Themes (DRDTs*), but also to the GSRs* (General Recommendation Strategies)



DRDT

WG2 Applications

Tools and infrastructures

DRDT1.1

DRDT1.2

DRDT1.3

DRDT1.4

Inner and central tracking with PID capability

Photo-detectors (PID)

Timing detectors (PID and trigger)

Genuine Trackers/Hodoscopes (large area muon systems, inner tracking/vertexing)

Calorimetry

TPCs as reaction and decay chambers (rare events, neutrino physics, nuclear physics)

WG1 Technologies

WG3 Gas and material studies

WG4 Detector physics, simulations and software tools

WG5 Electronics for gaseous detectors

WG6 Detector production

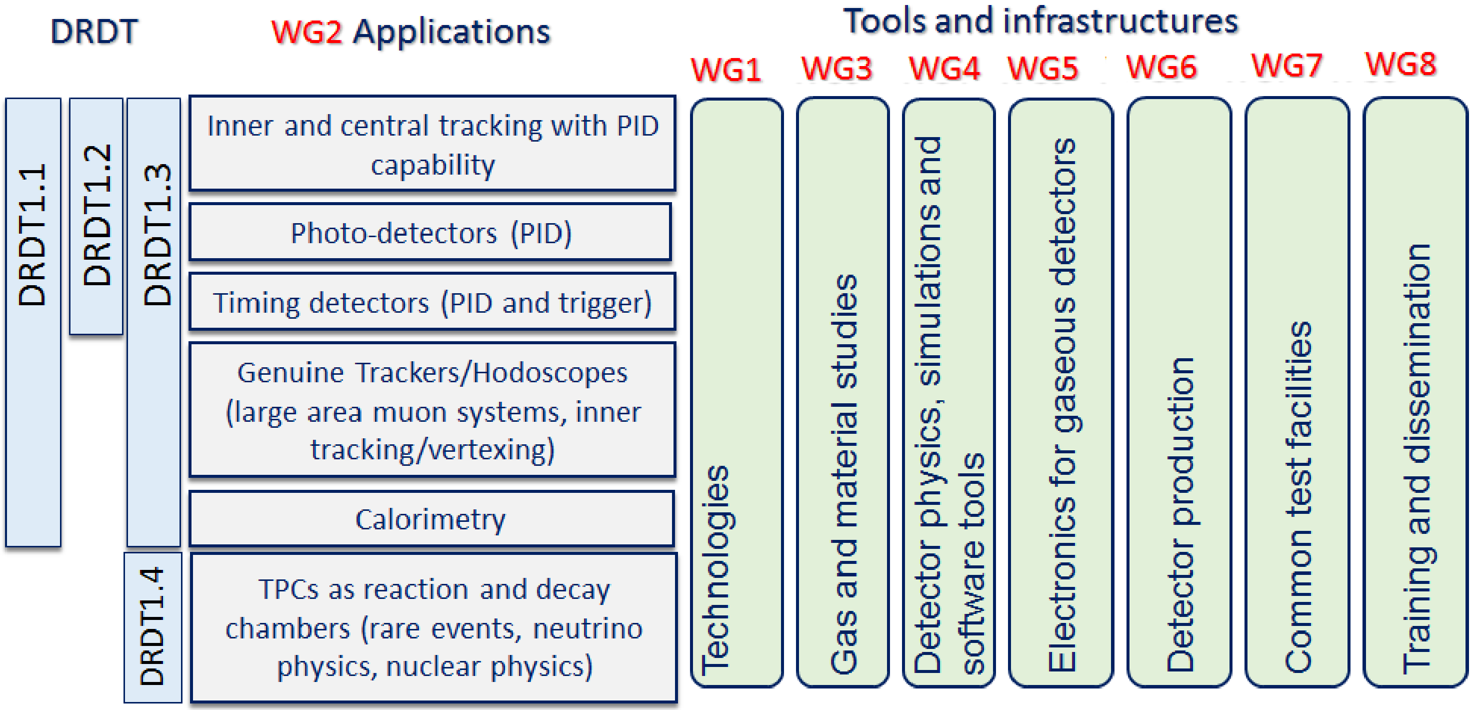
WG7 Common test facilities

WG8 Training and dissemination

* See backup for details

Digression

- Where, in the DRD1 scheme, current RD51 WG2 (Detector Physics and Performance)?
- **Shared** between WG1/WG2/WG3/WG4 topics ?



DRDT

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DRDT1.2

DRDT1.3

DRDT1.4

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WG5 Electronics for gaseous detectors

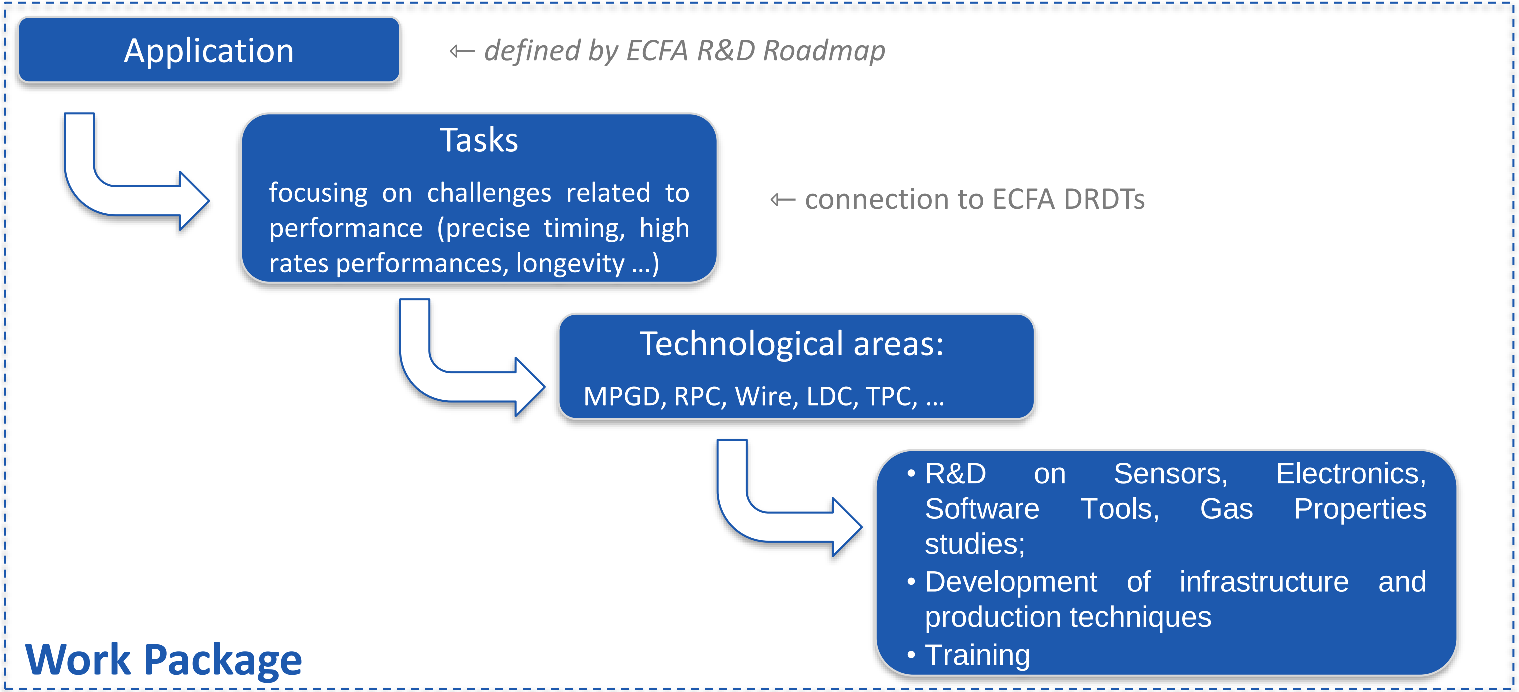
WG6 Detector production

WG7 Common test facilities

WG8 Training and dissemination

Work Packages

- **Strategic R&D** (according to the ECFA Detector R&D Roadmap) **is organized in Work Packages**
  - group activities of the Institutes with **shared research interests** around **Applications** with a focus on a **specific task(s)** devoted to a specific DRDT challenge, typically related to specific **Detector Technologies and** to the development of **specific tool or infrastructure**



Application

← *defined by ECFA R&D Roadmap*

Tasks

focusing on challenges related to performance (precise timing, high rates performances, longevity …)

← connection to ECFA DRDTs

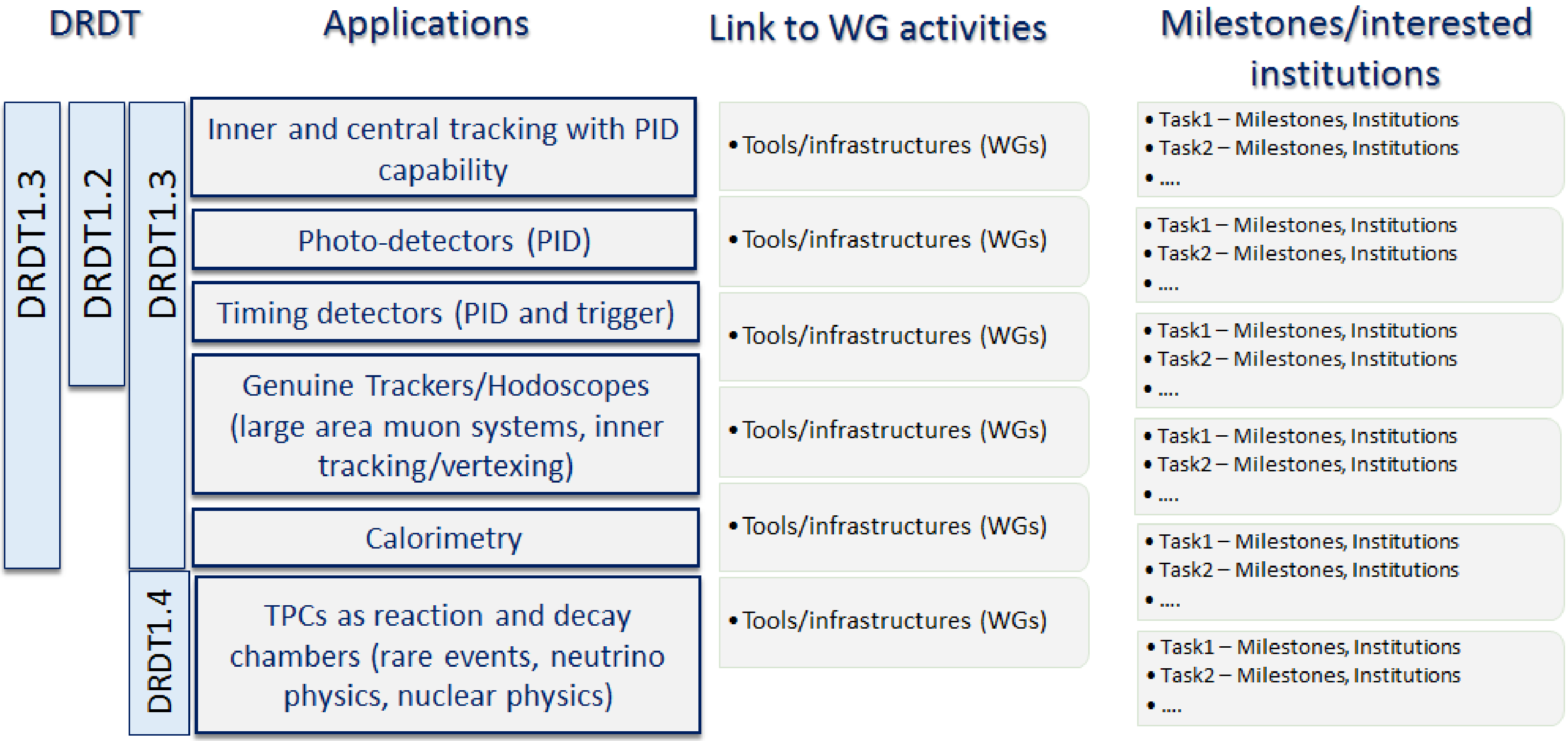
Technological areas:

MPGD, RPC, Wire, LDC, TPC, …

- R&D on Sensors, Electronics, Software Tools, Gas Properties studies;
- Development of infrastructure and production techniques
- Training

Work Package

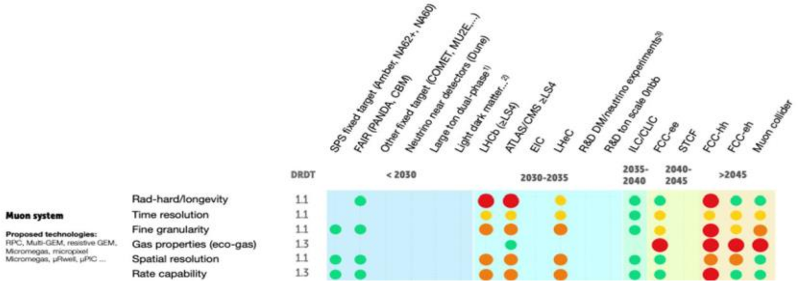
Work Packages



DRDT	Applications	Link to WG activities	Milestones/interested institutions
DRDT1.3 DRDT1.2 DRDT1.3	Inner and central tracking with PID capability	• Tools/infrastructures (WGs)	• Task1 – Milestones, Institutions • Task2 – Milestones, Institutions • ....
	Photo-detectors (PID)	• Tools/infrastructures (WGs)	• Task1 – Milestones, Institutions • Task2 – Milestones, Institutions • ....
	Timing detectors (PID and trigger)	• Tools/infrastructures (WGs)	• Task1 – Milestones, Institutions • Task2 – Milestones, Institutions • ....
	Genuine Trackers/Hodoscopes (large area muon systems, inner tracking/vertexing)	• Tools/infrastructures (WGs)	• Task1 – Milestones, Institutions • Task2 – Milestones, Institutions • ....
	Calorimetry	• Tools/infrastructures (WGs)	• Task1 – Milestones, Institutions • Task2 – Milestones, Institutions • ....
DRDT1.4	TPCs as reaction and decay chambers (rare events, neutrino physics, nuclear physics)	• Tools/infrastructures (WGs)	• Task1 – Milestones, Institutions • Task2 – Milestones, Institutions • ....

WP1: Genuine trackers/hodoscopes

(large area muon systems, tracking/vertexing)



		DRDT	< 2030						2030-2035						2035-2040	2040-2045		>2045		
			SPS fixed target (Amber, NA62+, NA60)	FAIR (PANDA, CBM)	Other fixed target (COMET, MU2E...)	Neutrino near detectors (Dune)	Large ton dual-phase$^{1)}$	Light dark matter...$^{2)}$	LHCb (≥LS4)	ATLAS/CMS ≥LS4	EIC	LHeC	R&D DM/neutrino experiments$^{3)}$	R&D ton scale 0nbb	ILC/CLIC	FCC-ee	STCF	FCC-hh	FCC-eh	Muon collider
Muon system	Rad-hard/longevity	1.1		🟢					🔴	🔴		🟡			🟢	🟢		🔴	🟢	🟢
	Time resolution	1.1							🟡	🟡		🟡			🟢	🟡		🟡	🟡	🟡
Proposed technologies: RPC, Multi-GEM, resistive GEM, Micromegas, micropixel Micromegas, μRwell, μPIC ...	Fine granularity	1.1	🟢	🟢					🟠	🟠		🟠			🟢	🟡		🔴	🟡	🟠
	Gas properties (eco-gas)	1.3								🟢						🔴		🔴	🔴	🔴
	Spatial resolution	1.1	🟢	🟢					🟠	🟠		🟠			🟢	🟢		🟠	🟠	🟢
	Rate capability	1.3	🟢	🟢					🟠	🟠		🟠			🟢	🟢		🔴	🟢	🟢

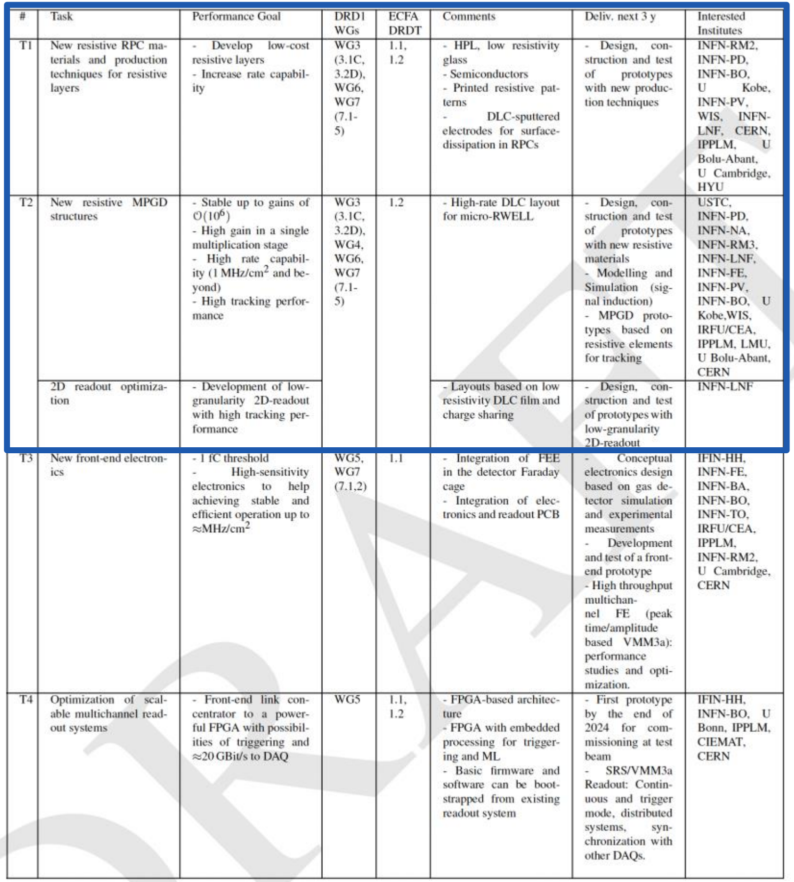
Challenges/tasks

- extend state-of-the-art rate capability and longevity by minimum one order of magnitude or more in the highest eta region (up to an order of MHz/cm^2)
- enable detectors reliably and efficiently working with suitable low GWP mixtures
- reaching the two objectives above can be favored in 3 ways:
  - low noise electronics integrated in a highly stable and noise immune Faraday cage
  - new detector geometries increasing the signal collection yield
  - use of innovative resistive material for suppressing discharges on the electrodes.
- Time resolution O(20ps) for timing applications and of 200-300 ps to identify the BC in a very high rate collider, to help in cutting the pile up and to boost the ability to measure particle velocity
- large series industrializes production

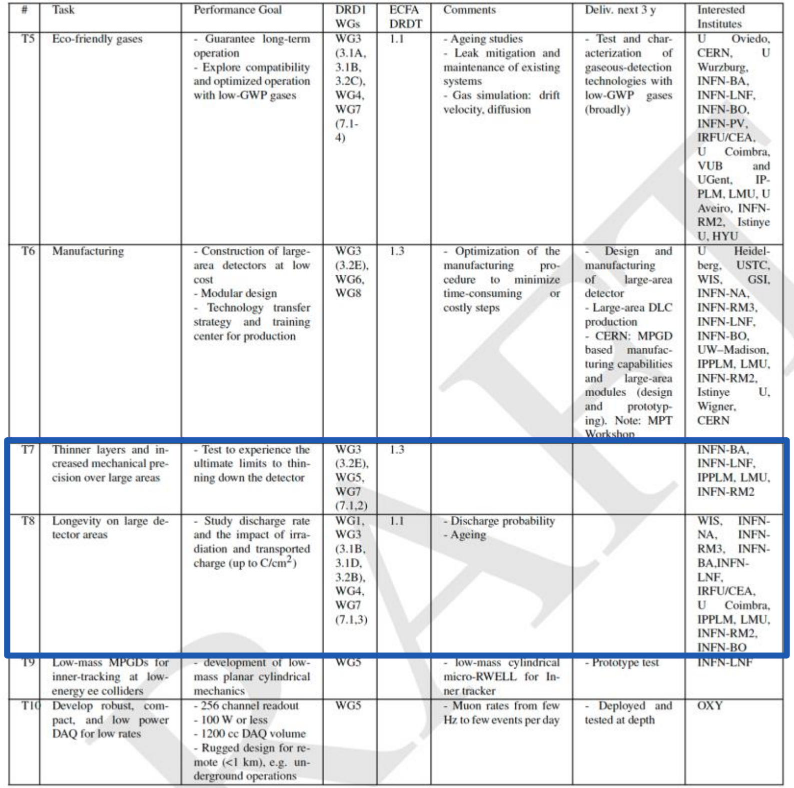
WP1: Genuine trackers/hodoscopes

(large area muon systems, tracking/vertexing)

WG1 (Technologies) – related



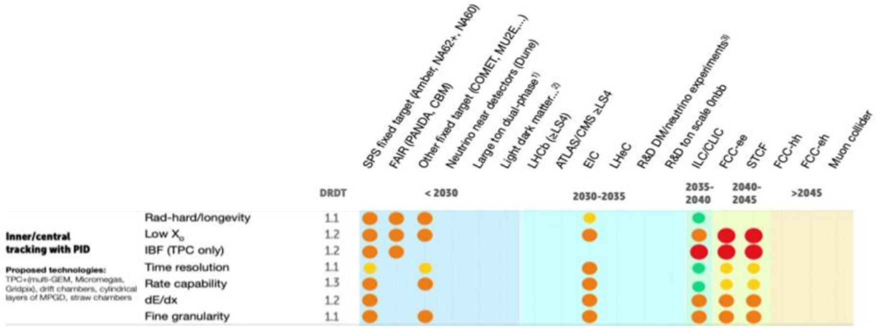
#	Task	Performance Goal	DRD1 WGs	ECFA DRDT	Comments	Deliv. next 3 y	Interested Institutes
T1	New resistive RPC materials and production techniques for resistive layers	- Develop low-cost resistive layers - Increase rate capability	WG3 (3.1C, 3.2D), WG6, WG7 (7.1-5)	1.1, 1.2	- HPL, low resistivity glass - Semiconductors - Printed resistive patterns - DLC-sputtered electrodes for surface-dissipation in RPCs	- Design, construction and test of prototypes with new production techniques	INFN-RM2, INFN-PD, INFN-BO, U Kobe, INFN-PV, WIS, INFN-LNF, CERN, IPPLM, U Bolu-Abant, U Cambridge, HYU
T2	New resistive MPGD structures	- Stable up to gains of $\mathcal{O}(10^6)$ - High gain in a single multiplication stage - High rate capability (1 MHz/cm^2 and beyond) - High tracking performance	WG3 (3.1C, 3.2D), WG4, WG6, WG7 (7.1-5)	1.2	- High-rate DLC layout for micro-RWELL	- Design, construction and test of prototypes with new resistive materials - Modelling and Simulation (signal induction) - MPGD prototypes based on resistive elements for tracking	USTC, INFN-PD, INFN-NA, INFN-RM3, INFN-LNF, INFN-FE, INFN-PV, INFN-BO, U Kobe,WIS, IRFU/CEA, IPPLM, LMU, U Bolu-Abant, CERN
	2D readout optimization	- Development of low-granularity 2D-readout with high tracking performance			- Layouts based on low resistivity DLC film and charge sharing	- Design, construction and test of prototypes with low-granularity 2D-readout	INFN-LNF
T3	New front-end electronics	- 1 fC threshold - High-sensitivity electronics to help achieving stable and efficient operation up to ≈MHz/cm^2	WG5, WG7 (7.1,2)	1.1	- Integration of FEE in the detector Faraday cage - Integration of electronics and readout PCB	- Conceptual electronics design based on gas detector simulation and experimental measurements - Development and test of a front-end prototype - High throughput multichannel FE (peak time/amplitude based VMM3a): performance studies and optimization.	IFIN-HH, INFN-FE, INFN-BA, INFN-BO, INFN-TO, IRFU/CEA, IPPLM, INFN-RM2, U Cambridge, CERN
T4	Optimization of scalable multichannel readout systems	- Front-end link concentrator to a powerful FPGA with possibilities of triggering and ≈20 GBit/s to DAQ	WG5	1.1, 1.2	- FPGA-based architecture - FPGA with embedded processing for triggering and ML - Basic firmware and software can be bootstrapped from existing readout system	- First prototype by the end of 2024 for commissioning at test beam - SRS/VMM3a Readout: Continuous and trigger mode, distributed systems, synchronization with other DAQs.	IFIN-HH, INFN-BO, U Bonn, IPPLM, CIEMAT, CERN

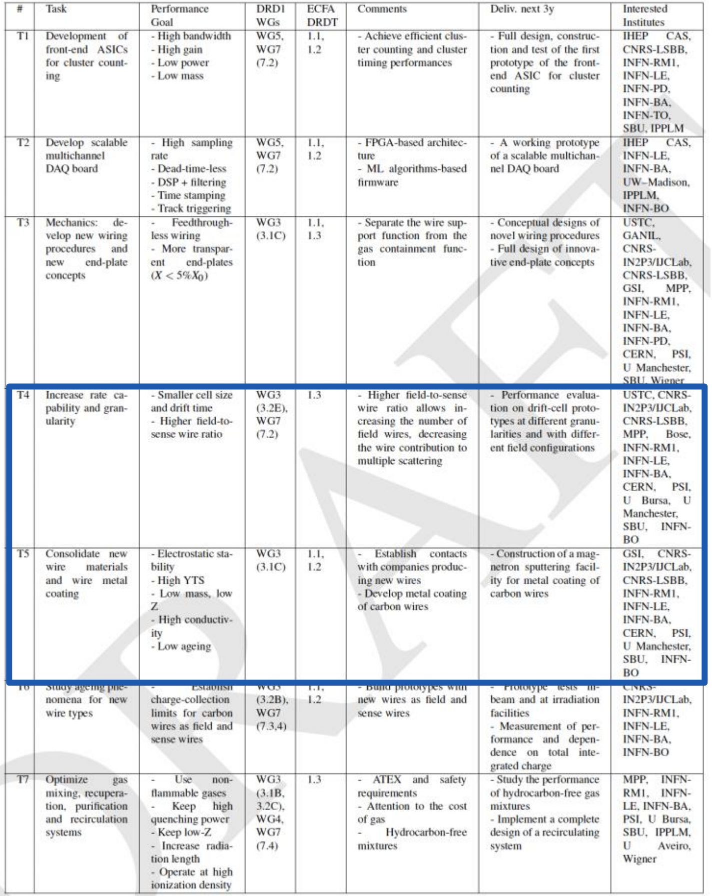


#	Task	Performance Goal	DRD1 WGs	ECFA DRDT	Comments	Deliv. next 3 y	Interested Institutes
T5	Eco-friendly gases	- Guarantee long-term operation - Explore compatibility and optimized operation with low-GWP gases	WG3 (3.1A, 3.1B, 3.2C), WG4, WG7 (7.1-4)	1.1	- Ageing studies - Leak mitigation and maintenance of existing systems - Gas simulation: drift velocity, diffusion	- Test and characterization of gaseous-detection technologies with low-GWP gases (broadly)	U Oviedo, CERN, U Wurzburg, INFN-BA, INFN-LNF, INFN-BO, INFN-PV, IRFU/CEA, U Coimbra, VUB and UGent, IPPLM, LMU, U Aveiro, INFN-RM2, Istinye U, HYU
T6	Manufacturing	- Construction of large-area detectors at low cost - Modular design - Technology transfer strategy and training center for production	WG3 (3.2E), WG6, WG8	1.3	- Optimization of the manufacturing procedure to minimize time-consuming or costly steps	- Design and manufacturing of large-area detector - Large-area DLC production - CERN: MPGD based manufacturing capabilities and large-area modules (design and prototyping). Note: MPT Workshop	U Heidelberg, USTC, WIS, GSI, INFN-NA, INFN-RM3, INFN-LNF, INFN-BO, UW–Madison, IPPLM, LMU, INFN-RM2, Istinye U, Wigner, CERN
T7	Thinner layers and increased mechanical precision over large areas	- Test to experience the ultimate limits to thinning down the detector	WG3 (3.2E), WG5, WG7 (7.1,2)	1.3			INFN-BA, INFN-LNF, IPPLM, LMU, INFN-RM2
T8	Longevity on large detector areas	- Study discharge rate and the impact of irradiation and transported charge (up to C/cm^2)	WG1, WG3 (3.1B, 3.1D, 3.2B), WG4, WG7 (7.1,3)	1.1	- Discharge probability - Ageing		WIS, INFN-NA, INFN-RM3, INFN-BA,INFN-LNF, IRFU/CEA, U Coimbra, IPPLM, LMU, INFN-RM2, INFN-BO
T9	Low-mass MPGDs for inner-tracking at low-energy ee colliders	- development of low-mass planar cylindrical mechanics	WG5		- low-mass cylindrical micro-RWELL for Inner tracker	- Prototype test	INFN-LNF
T10	Develop robust, compact, and low power DAQ for low rates	- 256 channel readout - 100 W or less - 1200 cc DAQ volume - Rugged design for remote (<1 km), e.g. underground operations	WG5		- Muon rates from few Hz to few events per day	- Deployed and tested at depth	OXY

WP2: Inner and central tracking with PID

(DRIFT CHAMBERS)





#	Task	Performance Goal	DRD1 WGs	ECFA DRDT	Comments	Deliv. next 3y	Interested Institutes
T1	Development of front-end ASICs for cluster counting	- High bandwidth - High gain - Low power - Low mass	WG5, WG7 (7.2)	1.1, 1.2	- Achieve efficient cluster counting and cluster timing performances	- Full design, construction and test of the first prototype of the front-end ASIC for cluster counting	IHEP CAS, CNRS-LSBB, INFN-RM1, INFN-LE, INFN-PD, INFN-BA, INFN-TO, SBU, IPPLM
T2	Develop scalable multichannel DAQ board	- High sampling rate - Dead-time-less - DSP + filtering - Time stamping - Track triggering	WG5, WG7 (7.2)	1.1, 1.2	- FPGA-based architecture - ML algorithms-based firmware	- A working prototype of a scalable multichannel DAQ board	IHEP CAS, INFN-LE, INFN-BA, UW–Madison, IPPLM, INFN-BO
T3	Mechanics: develop new wiring procedures and new end-plate concepts	- Feedthrough-less wiring - More transparent end-plates ($X < 5\% X_0$)	WG3 (3.1C)	1.1, 1.3	- Separate the wire support function from the gas containment function	- Conceptual designs of novel wiring procedures - Full design of innovative end-plate concepts	USTC, GANIL, CNRS-IN2P3/IJCLab, CNRS-LSBB, GSI, MPP, INFN-RM1, INFN-LE, INFN-BA, INFN-PD, CERN, PSI, U Manchester, SBU, Wigner
T4	Increase rate capability and granularity	- Smaller cell size and drift time - Higher field-to-sense wire ratio	WG3 (3.2E), WG7 (7.2)	1.3	- Higher field-to-sense wire ratio allows increasing the number of field wires, decreasing the wire contribution to multiple scattering	- Performance evaluation on drift-cell prototypes at different granularities and with different field configurations	USTC, CNRS-IN2P3/IJCLab, CNRS-LSBB, MPP, Bose, INFN-RM1, INFN-LE, INFN-BA, CERN, PSI, U Bursa, U Manchester, SBU, INFN-BO
T5	Consolidate new wire materials and wire metal coating	- Electrostatic stability - High YTS - Low mass, low Z - High conductivity - Low ageing	WG3 (3.1C)	1.1, 1.2	- Establish contacts with companies producing new wires - Develop metal coating of carbon wires	- Construction of a magnetron sputtering facility for metal coating of carbon wires	GSI, CNRS-IN2P3/IJCLab, CNRS-LSBB, INFN-RM1, INFN-LE, INFN-BA, CERN, PSI, U Manchester, SBU, INFN-BO
T6	Study ageing phenomena for new wire types	- Establish charge-collection limits for carbon wires as field and sense wires	WG3 (3.2B), WG7 (7.3,4)	1.1, 1.2	- Build prototypes with new wires as field and sense wires	- Prototype tests in-beam and at irradiation facilities - Measurement of performance and dependence on total integrated charge	CNRS-IN2P3/IJCLab, INFN-RM1, INFN-LE, INFN-BA, INFN-BO
T7	Optimize gas mixing, recuperation, purification and recirculation systems	- Use non-flammable gases - Keep high quenching power - Keep low-Z - Increase radiation length - Operate at high ionization density	WG3 (3.1B, 3.2C), WG4, WG7 (7.4)	1.3	- ATEX and safety requirements - Attention to the cost of gas - Hydrocarbon-free mixtures	- Study the performance of hydrocarbon-free gas mixtures - Implement a complete design of a recirculating system	MPP, INFN-RM1, INFN-LE, INFN-BA, PSI, U Bursa, SBU, IPPLM, U Aveiro, Wigner

Challenges/tasks

- **Mechanics: new wiring procedures, new wire materials**

  High gas gains ~**5×10⁵**, required for the application of the cluster counting techniques, high granularities (small cell size, order of 1 cm), long wires (order of 4-5 m) and electrostatic stability demand studies on new light materials with high YTS for wires.

- **Electronics: on-line, real time data processing algorithms**

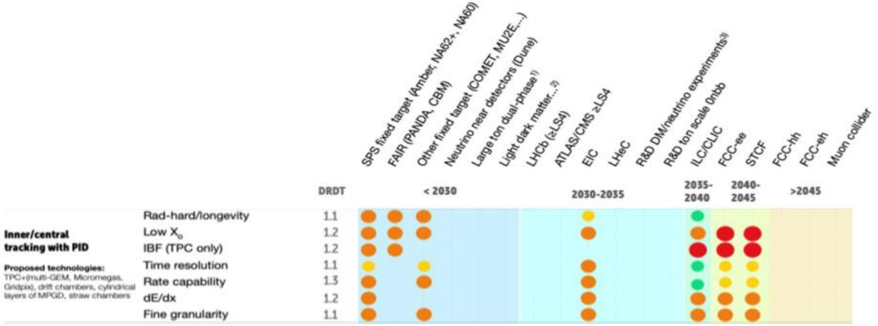
  Waveform digitizers, signal processing for cluster counting exploiting new data processing algorithms

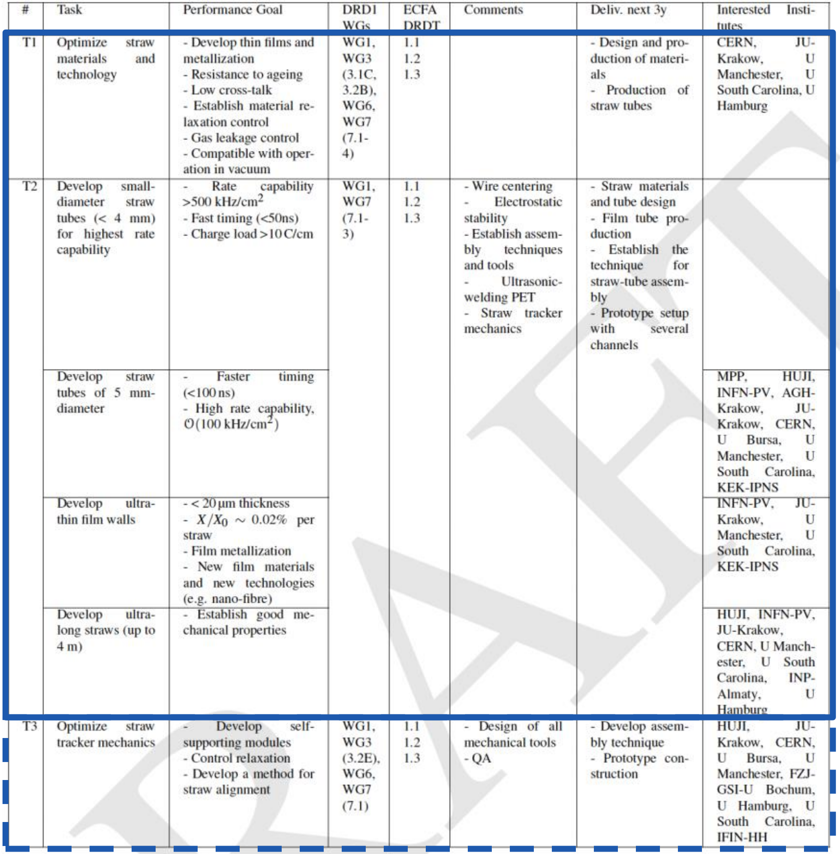
- **Hydrocarbon-free gas mixtures / recirculating gas systems**

  Safety requirements (**ATEX**) on flammable gases and ever-increasing costs of noble gas

WP3: Inner and central tracking with PID

(STRAW CHAMBERS)





#	Task	Performance Goal	DRD1 WGs	ECFA DRDT	Comments	Deliv. next 3y	Interested Institutes
T1	Optimize straw materials and technology	- Develop thin films and metallization - Resistance to ageing - Low cross-talk - Establish material relaxation control - Gas leakage control - Compatible with operation in vacuum	WG1, WG3 (3.1C, 3.2B), WG6, WG7 (7.1-4)	1.1 1.2 1.3		- Design and production of materials - Production of straw tubes	CERN, JU-Krakow, U Manchester, U South Carolina, U Hamburg
T2	Develop small-diameter straw tubes (< 4 mm) for highest rate capability	- Rate capability >500 kHz/cm^2 - Fast timing (<50ns) - Charge load >10 C/cm	WG1, WG7 (7.1-3)	1.1 1.2 1.3	- Wire centering - Electrostatic stability - Establish assembly techniques and tools - Ultrasonic-welding PET - Straw tracker mechanics	- Straw materials and tube design - Film tube production - Establish the technique for straw-tube assembly - Prototype setup with several channels	
	Develop straw tubes of 5 mm-diameter	- Faster timing (<100 ns) - High rate capability, $\mathcal{O}$(100 kHz/cm^2)					MPP, HUJI, INFN-PV, AGH-Krakow, JU-Krakow, CERN, U Bursa, U Manchester, U South Carolina, KEK-IPNS
	Develop ultra-thin film walls	- < 20 µm thickness - $X/X_0 \sim 0.02\%$ per straw - Film metallization - New film materials and new technologies (e.g. nano-fibre)					INFN-PV, JU-Krakow, U Manchester, U South Carolina, KEK-IPNS
	Develop ultra-long straws (up to 4 m)	- Establish good mechanical properties					HUJI, INFN-PV, JU-Krakow, CERN, U Manchester, U South Carolina, INP-Almaty, U Hamburg
T3	Optimize straw tracker mechanics	- Develop self-supporting modules - Control relaxation - Develop a method for straw alignment	WG1, WG3 (3.2E), WG6, WG7 (7.1)	1.1 1.2 1.3	- Design of all mechanical tools - QA	- Develop assembly technique - Prototype construction	HUJI, JU-Krakow, CERN, U Bursa, U Manchester, FZJ-GSI-U Bochum, U Hamburg, U South Carolina, IFIN-HH

Challenges/tasks

- **Mechanics: thinner, smaller diameter, longer straw tubes / mechanical stability**

  6+6 µm mylar + 3 µm glue wound-type or 25 µm seamless (resistive) type, few mm diameter, several m length /self-supporting structures

- **Material studies**

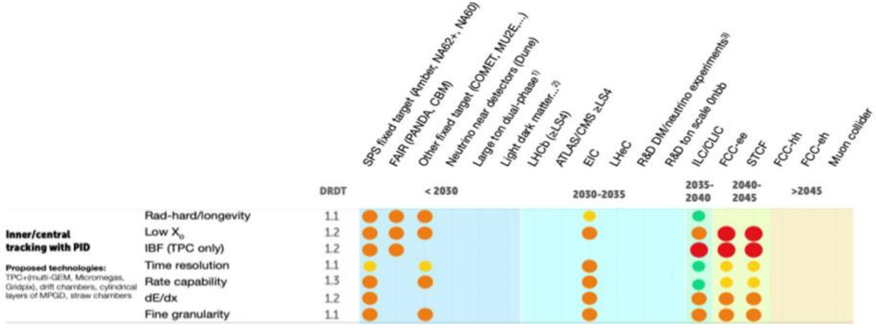
  Creep under tension (tension relaxation), gas leakage (operation under vacuum or overpressure)

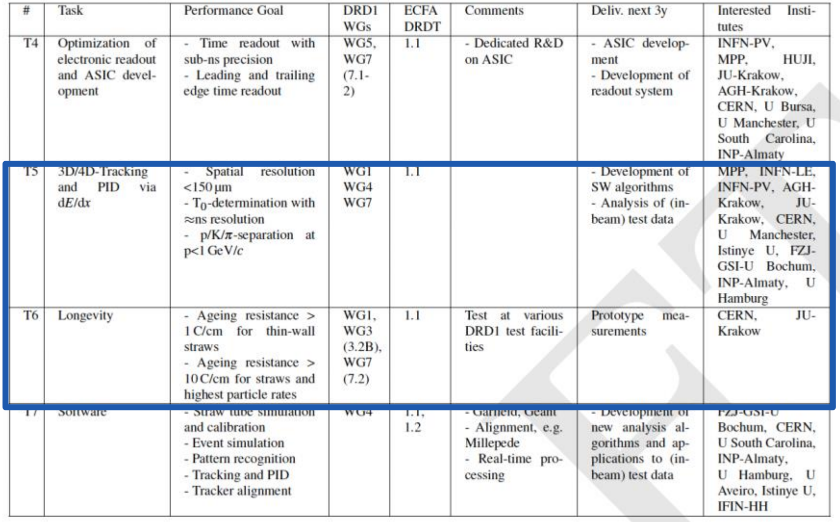
- **Electronics**

  Leading and trailing time resolution for 4D measurements and for dE/dx with time over threshold

WP3: Inner and central tracking with PID

(STRAW CHAMBERS)





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T4	Optimization of electronic readout and ASIC development	- Time readout with sub-ns precision - Leading and trailing edge time readout	WG5, WG7 (7.1-2)	1.1	- Dedicated R&D on ASIC	- ASIC development - Development of readout system	INFN-PV, MPP, HUJI, JU-Krakow, AGH-Krakow, CERN, U Bursa, U Manchester, U South Carolina, INP-Almaty
T5	3D/4D-Tracking and PID via dE/dx	- Spatial resolution <150 µm - T_0-determination with ≈ns resolution - p/K/π-separation at p<1 GeV/c	WG1 WG4 WG7	1.1		- Development of SW algorithms - Analysis of (in-beam) test data	MPP, INFN-LE, INFN-PV, AGH-Krakow, JU-Krakow, CERN, U Manchester, Istinye U, FZJ-GSI-U Bochum, INP-Almaty, U Hamburg
T6	Longevity	- Ageing resistance > 1 C/cm for thin-wall straws - Ageing resistance > 10 C/cm for straws and highest particle rates	WG1, WG3 (3.2B), WG7 (7.2)	1.1	Test at various DRD1 test facilities	Prototype measurements	CERN, JU-Krakow
T7	Software	- Straw tube simulation and calibration - Event simulation - Pattern recognition - Tracking and PID - Tracker alignment	WG4	1.1, 1.2	- Garfield, Geant - Alignment, e.g. Millepede - Real-time processing	- Development of new analysis algorithms and applications to (in-beam) test data	FZJ-GSI-U Bochum, CERN, U South Carolina, INP-Almaty, U Hamburg, U Aveiro, Istinye U, IFIN-HH

Challenges/tasks

- **Mechanics: thinner, smaller diameter, longer straw tubes / mechanical stability**

  6+6 µm mylar + 3 µm glue wound-type or 25 µm seamless (resistive) type, few mm diameter, several m length /self-supporting structures

- **Material studies**

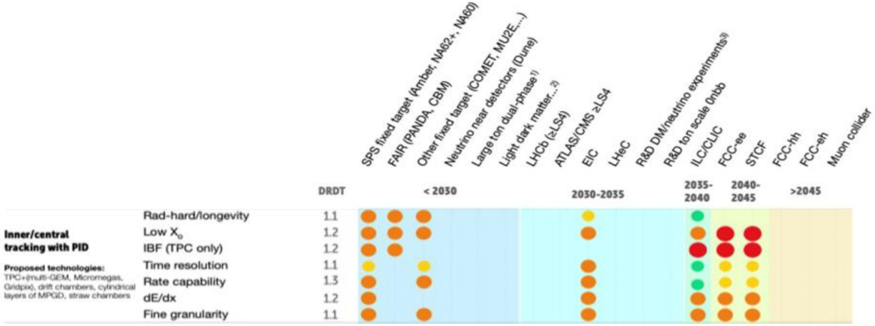
  Creep under tension (tension relaxation), gas leakage (operation under vacuum or overpressure)

- **Electronics**

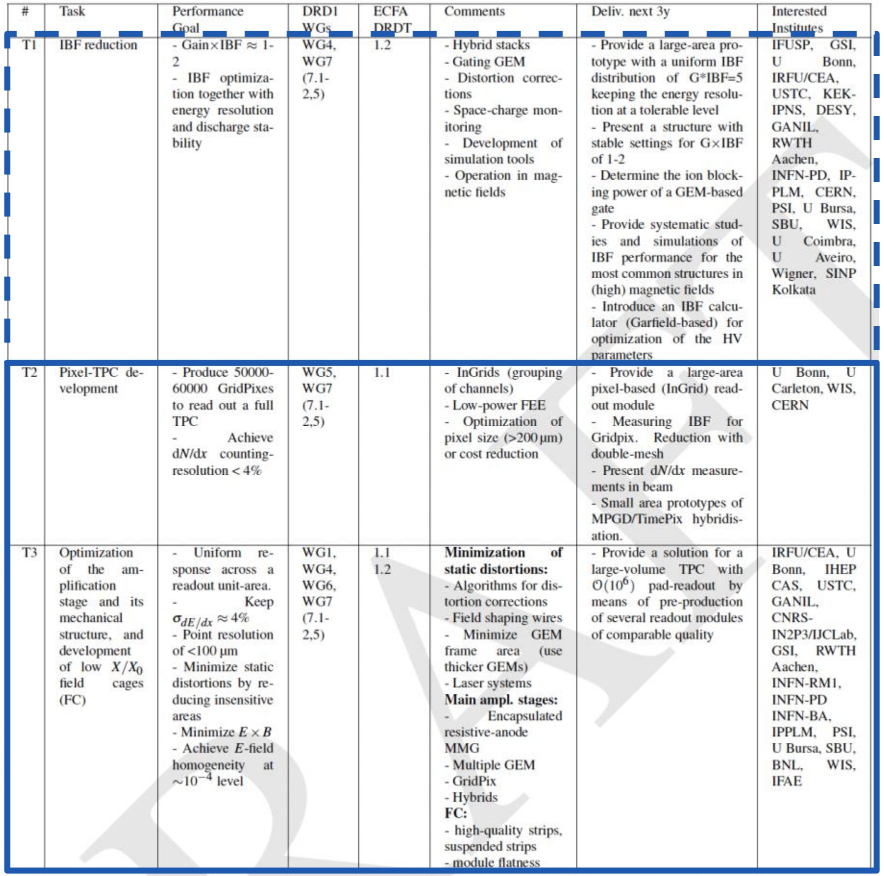
  Leading and trailing time resolution for 4D measurements and for dE/dx with time over threshold

WP4: Inner and central tracking with PID

(LARGE VOLUME TRACKING TPCS)



		DRDT	SPS fixed target (Amber, NA62+, NA60)	FAIR (PANDA, CBM)	Other fixed target (COMET, MU2E,...)	Neutrino near detectors (Dune)	Large ton dual-phase 1)	Light dark matter... 2)	LHCb (≥LS4)	ATLAS/CMS ≥LS4	EIC	LHeC	R&D DM/neutrino experiments 3)	R&D ton scale 0nbb	ILC/CLIC	FCC-ee	STCF	FCC-hh	FCC-eh	Muon collider
			< 2030							2030-2035					2035-2040	2040-2045		>2045		
Inner/central tracking with PID **Proposed technologies:** TPC+(multi-GEM, Micromegas, Gridpix), drift chambers, cylindrical layers of MPGD, straw chambers	Rad-hard/longevity	1.1	🟠	🟠	🟠						🟡				🟢					
	Low X_0	1.2	🟠	🟠	🟠						🟠				🟠	🔴	🔴			
	IBF (TPC only)	1.2	🟠	🟠											🔴	🔴	🔴			
	Time resolution	1.1	🟡		🟡						🟠				🟢	🟡	🟡			
	Rate capability	1.3	🟠		🟠						🟠				🟢	🟡	🟡			
	dE/dx	1.2	🟠								🟠				🟠	🟠	🟠			
	Fine granularity	1.1	🟠		🟠						🟠				🟠	🟠	🟠			



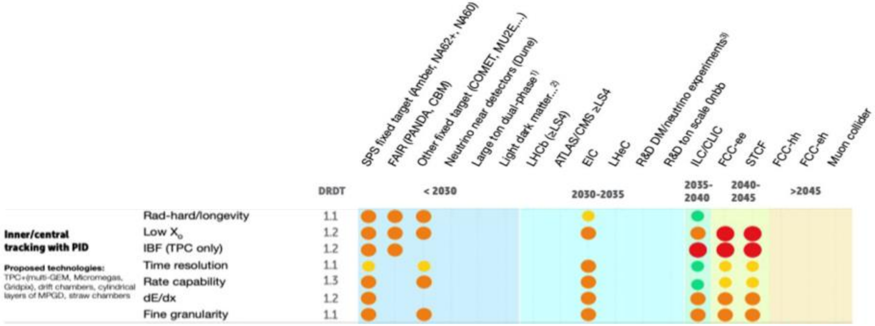
#	Task	Performance Goal	DRD1 WGs	ECFA DRDT	Comments	Deliv. next 3y	Interested Institutes
T1	IBF reduction	- Gain×IBF ≈ 1-2 - IBF optimization together with energy resolution and discharge stability	WG4, WG7 (7.1-2,5)	1.2	- Hybrid stacks - Gating GEM - Distortion corrections - Space-charge monitoring - Development of simulation tools - Operation in magnetic fields	- Provide a large-area prototype with a uniform IBF distribution of G*IBF=5 keeping the energy resolution at a tolerable level - Present a structure with stable settings for G×IBF of 1-2 - Determine the ion blocking power of a GEM-based gate - Provide systematic studies and simulations of IBF performance for the most common structures in (high) magnetic fields - Introduce an IBF calculator (Garfield-based) for optimization of the HV parameters	IFUSP, GSI, U Bonn, IRFU/CEA, USTC, KEK-IPNS, DESY, GANIL, RWTH Aachen, INFN-PD, IP-PLM, CERN, PSI, U Bursa, SBU, WIS, U Coimbra, U Aveiro, Wigner, SINP Kolkata
T2	Pixel-TPC development	- Produce 50000-60000 GridPixes to read out a full TPC - Achieve d*N*/dx counting-resolution < 4%	WG5, WG7 (7.1-2,5)	1.1	- InGrids (grouping of channels) - Low-power FEE - Optimization of pixel size (>200 µm) or cost reduction	- Provide a large-area pixel-based (InGrid) readout module - Measuring IBF for Gridpix. Reduction with double-mesh - Present d*N*/dx measurements in beam - Small area prototypes of MPGD/TimePix hybridisation.	U Bonn, U Carleton, WIS, CERN
T3	Optimization of the amplification stage and its mechanical structure, and development of low X/X_0 field cages (FC)	- Uniform response across a readout unit-area. - Keep $\sigma_{dE/dx} \approx 4\%$ - Point resolution of <100 µm - Minimize static distortions by reducing insensitive areas - Minimize $E \times B$ - Achieve E-field homogeneity at $\sim 10^{-4}$ level	WG1, WG4, WG6, WG7 (7.1-2,5)	1.1 1.2	**Minimization of static distortions:** - Algorithms for distortion corrections - Field shaping wires - Minimize GEM frame area (use thicker GEMs) - Laser systems **Main ampl. stages:** - Encapsulated resistive-anode MMG - Multiple GEM - GridPix - Hybrids **FC:** - high-quality strips, suspended strips - module flatness	- Provide a solution for a large-volume TPC with $\mathcal{O}(10^6)$ pad-readout by means of pre-production of several readout modules of comparable quality	IRFU/CEA, U Bonn, IHEP CAS, USTC, GANIL, CNRS-IN2P3/IJCLab, GSI, RWTH Aachen, INFN-RM1, INFN-PD INFN-BA, IPPLM, PSI, U Bursa, SBU, BNL, WIS, IFAE

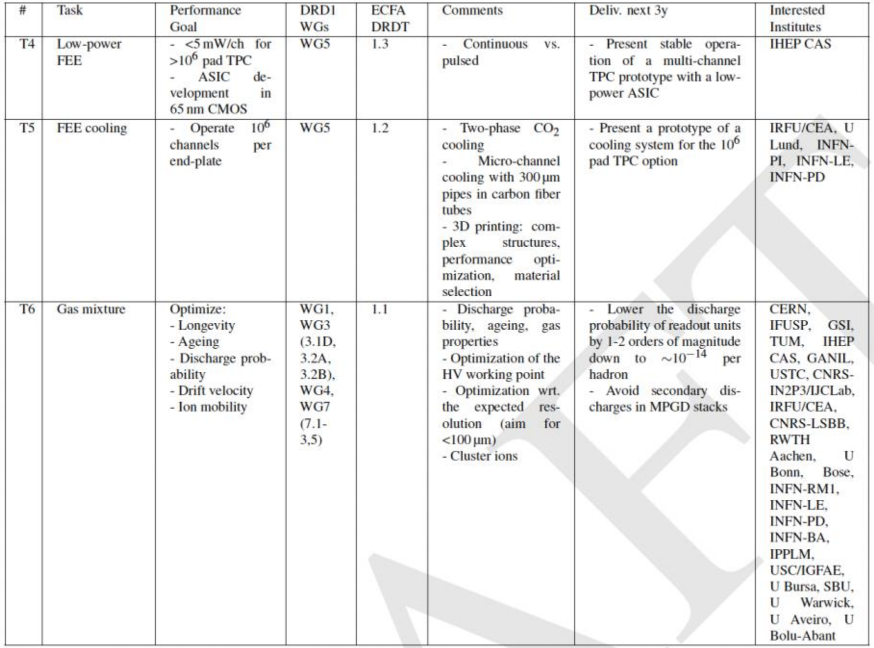
Challenges/tasks

- High rate,
- Low mass,
- Granularity,
- dE/dx & cluster counting
- Ion backflow suppression,
- Gas mixture optimization and Eco gas mixtures

WP4: Inner and central tracking with PID

(LARGE VOLUME TRACKING TPCS)



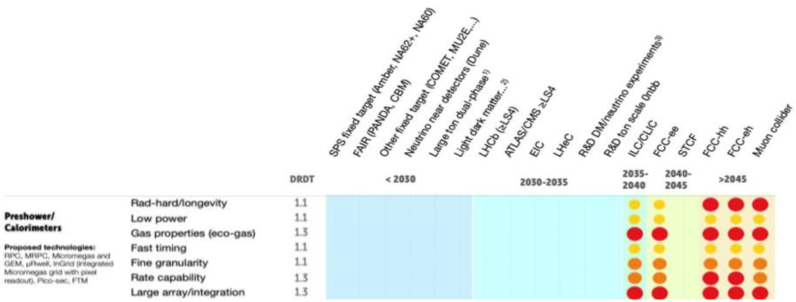


#	Task	Performance Goal	DRD1 WGs	ECFA DRDT	Comments	Deliv. next 3y	Interested Institutes
T4	Low-power FEE	- <5 mW/ch for >10^6 pad TPC - ASIC development in 65 nm CMOS	WG5	1.3	- Continuous vs. pulsed	- Present stable operation of a multi-channel TPC prototype with a low-power ASIC	IHEP CAS
T5	FEE cooling	- Operate 10^6 channels per end-plate	WG5	1.2	- Two-phase CO_2 cooling - Micro-channel cooling with 300 µm pipes in carbon fiber tubes - 3D printing: complex structures, performance optimization, material selection	- Present a prototype of a cooling system for the 10^6 pad TPC option	IRFU/CEA, U Lund, INFN-PI, INFN-LE, INFN-PD
T6	Gas mixture	Optimize: - Longevity - Ageing - Discharge probability - Drift velocity - Ion mobility	WG1, WG3 (3.1D, 3.2A, 3.2B), WG4, WG7 (7.1-3,5)	1.1	- Discharge probability, ageing, gas properties - Optimization of the HV working point - Optimization wrt. the expected resolution (aim for <100 µm) - Cluster ions	- Lower the discharge probability of readout units by 1-2 orders of magnitude down to $\sim 10^{-14}$ per hadron - Avoid secondary discharges in MPGD stacks	CERN, IFUSP, GSI, TUM, IHEP CAS, GANIL, USTC, CNRS-IN2P3/IJCLab, IRFU/CEA, CNRS-LSBB, RWTH Aachen, U Bonn, Bose, INFN-RM1, INFN-LE, INFN-PD, INFN-BA, IPPLM, USC/IGFAE, U Bursa, SBU, U Warwick, U Aveiro, U Bolu-Abant

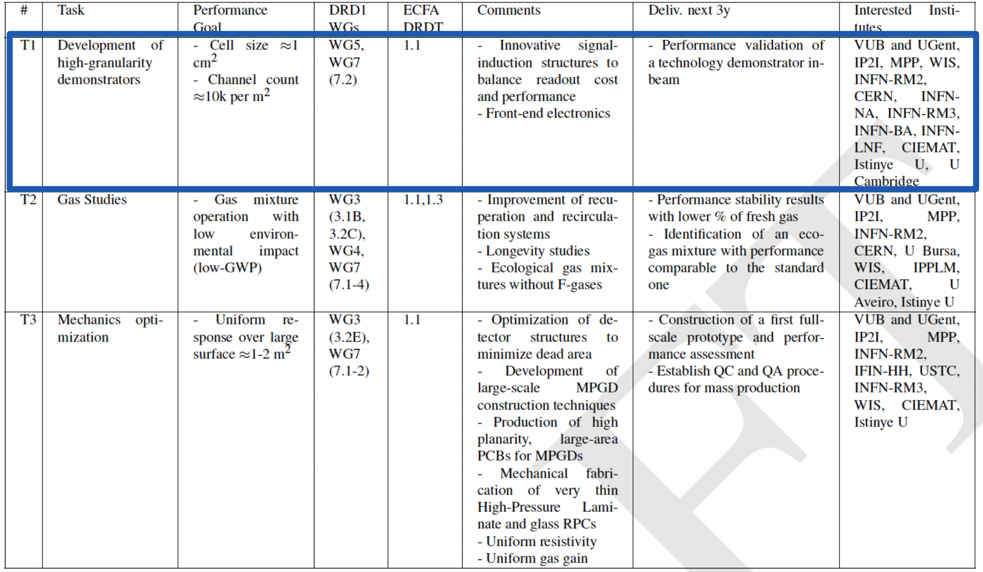
Challenges/tasks

- High rate,
- Low mass,
- Granularity,
- dE/dx & cluster counting
- Ion backflow suppression,
- Gas mixture optimization and Eco gas mixtures

WP5: Calorimetry



		DRDT	< 2030						2030-2035								2035-2040	2040-2045		>2045		
			SPS fixed target (Amber, NA62+, NA60)	FAIR (PANDA, CBM)	Other fixed target (COMET, MU2E,...)	Neutrino near detectors (Dune)	Large ton dual-phase 1)	Light dark matter... 2)	LHCb (≥LS4)	ATLAS/CMS ≥LS4	EIC	LHeC	R&D DM/neutrino experiments 3)	R&D ton scale 0nbb	ILC/CLIC	FCC-ee	STCF	FCC-hh	FCC-eh	Muon collider
Preshower/ Calorimeters	Rad-hard/longevity	1.1													🟡	🟡		🔴	🔴	🔴
	Low power	1.1													🟡	🟡		🟡	🟡	🟡
Proposed technologies: RPC, MRPC, Micromegas and GEM, µRwell, InGrid (integrated Micromegas grid with pixel readout), Pico-sec, FTM	Gas properties (eco-gas)	1.3													🔴	🔴		🔴	🔴	🔴
	Fast timing	1.1													🟡	🟡		🟡	🟡	🟡
	Fine granularity	1.1													🟠	🟠		🟠	🟠	🟠
	Rate capability	1.3													🟠	🟠		🔴	🔴	🟠
	Large array/integration	1.3													🔴	🔴		🔴	🔴	🔴



#	Task	Performance Goal	DRD1 WGs	ECFA DRDT	Comments	Deliv. next 3y	Interested Institutes
T1	Development of high-granularity demonstrators	- Cell size $\approx$1 cm^2 - Channel count $\approx$10k per m^2	WG5, WG7 (7.2)	1.1	- Innovative signal-induction structures to balance readout cost and performance - Front-end electronics	- Performance validation of a technology demonstrator in-beam	VUB and UGent, IP2I, MPP, WIS, INFN-RM2, CERN, INFN-NA, INFN-RM3, INFN-BA, INFN-LNF, CIEMAT, Istinye U, U Cambridge
T2	Gas Studies	- Gas mixture operation with low environmental impact (low-GWP)	WG3 (3.1B, 3.2C), WG4, WG7 (7.1-4)	1.1,1.3	- Improvement of recuperation and recirculation systems - Longevity studies - Ecological gas mixtures without F-gases	- Performance stability results with lower % of fresh gas - Identification of an eco-gas mixture with performance comparable to the standard one	VUB and UGent, IP2I, MPP, INFN-RM2, CERN, U Bursa, WIS, IPPLM, CIEMAT, U Aveiro, Istinye U
T3	Mechanics optimization	- Uniform response over large surface $\approx$1-2 m^2	WG3 (3.2E), WG7 (7.1-2)	1.1	- Optimization of detector structures to minimize dead area - Development of large-scale MPGD construction techniques - Production of high planarity, large-area PCBs for MPGDs - Mechanical fabrication of very thin High-Pressure Laminate and glass RPCs - Uniform resistivity - Uniform gas gain	- Construction of a first full-scale prototype and performance assessment - Establish QC and QA procedures for mass production	VUB and UGent, IP2I, MPP, INFN-RM2, IFIN-HH, USTC, INFN-RM3, WIS, CIEMAT, Istinye U

Challenges to develop large detector area

- Uniformity of the response and dynamic energy range
- Rate capability (x resistive material detector): 1 kHz/cm^2
- Time resolution O(100ps)

Not necessarily for large-area:

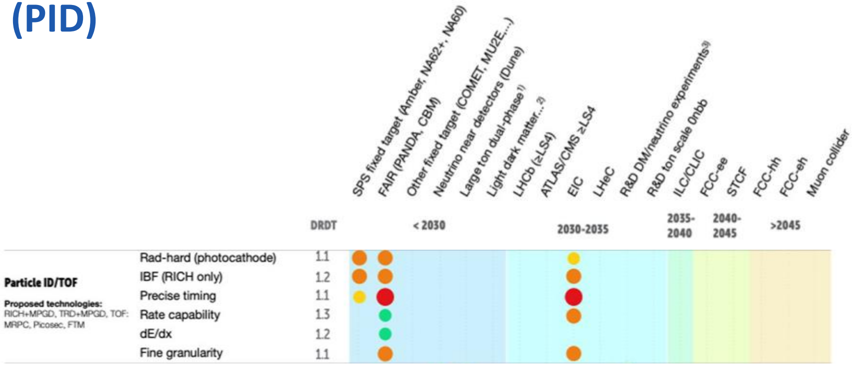
+ Eco-gas mixture
+ Stable performance (gas gain, time resolution, etc)
+ High radiation hardness

Technologies:

RPC, Micromegas, GEM, RWELL/RPWELL, micro-RWELL, gridPix, PICOSEC, FTM.

WP6: Photo-detectors

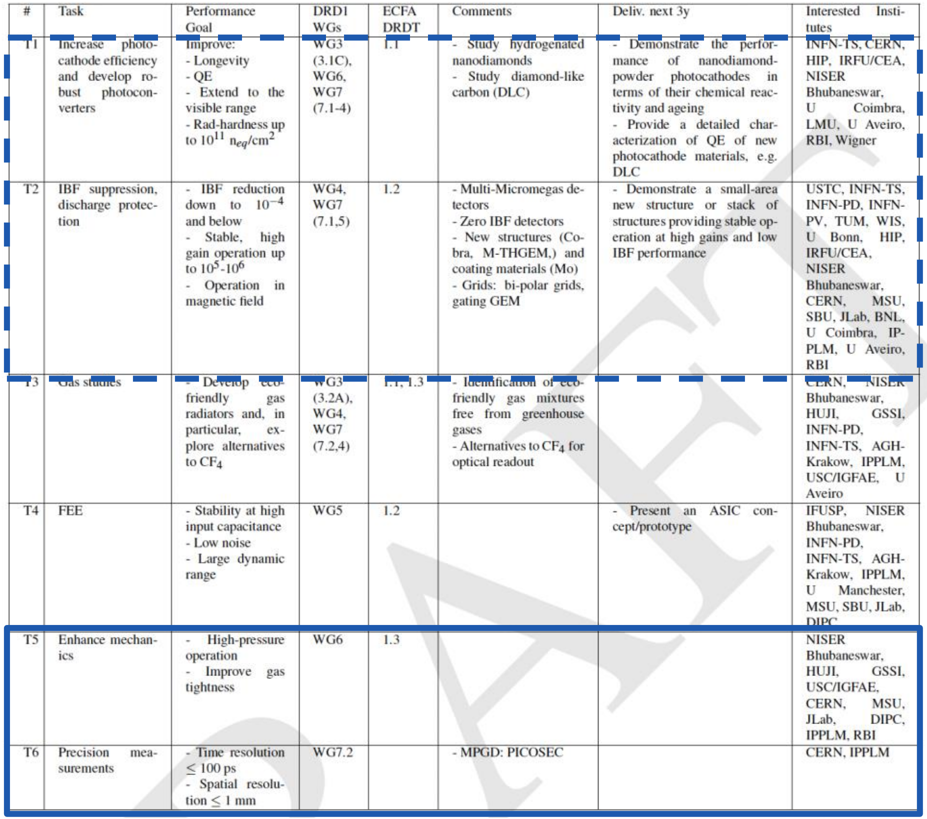
(PID)



		DRDT	< 2030						2030-2035						2035-2040	2040-2045		>2045		
			SPS fixed target (Amber, NA62+, NA60)	FAIR (PANDA, CBM)	Other fixed target (COMET, MU2E,...)	Neutrino near detectors (Dune)	Large ton dual-phase $^{1)}$	Light dark matter... $^{2)}$	LHCb (≥LS4)	ATLAS/CMS ≥LS4	EIC	LHeC	R&D DM/neutrino experiments $^{3)}$	R&D ton scale 0nbb	ILC/CLIC	FCC-ee	STCF	FCC-hh	FCC-eh	Muon collider
Particle ID/TOF **Proposed technologies:** RICH+MPGD, TRD+MPGD, TOF: MRPC, Picosec, FTM	Rad-hard (photocathode)	1.1	🟠	🟠							🟡									
	IBF (RICH only)	1.2	🟠	🟠							🟠									
	Precise timing	1.1	🟡	🔴							🔴									
	Rate capability	1.3		🟢							🟠									
	dE/dx	1.2		🟢																
	Fine granularity	1.1		🟠							🟠									

Challenges/tasks

- Preserve the photocathode efficiency by IBF and more robust photoconverters
- Very low noise, large dynamic range of the FEE
- Separate the TR radiation and the ionization process



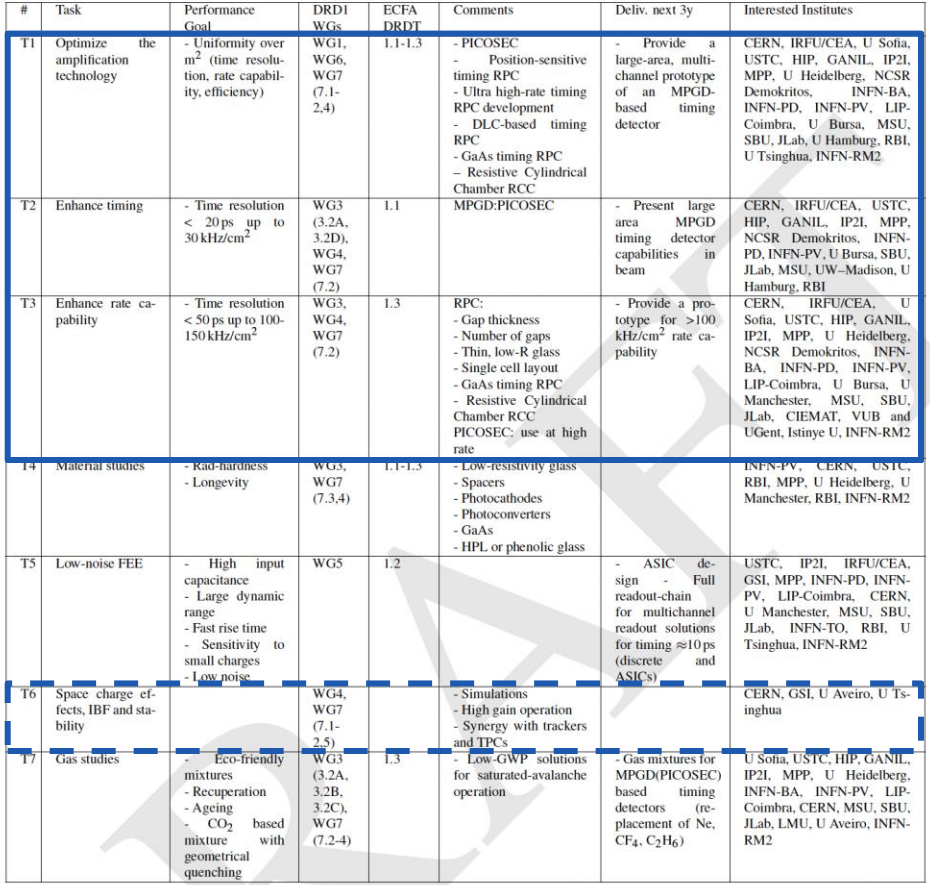
#	Task	Performance Goal	DRD1 WGs	ECFA DRDT	Comments	Deliv. next 3y	Interested Institutes
T1	Increase photocathode efficiency and develop robust photoconverters	Improve: - Longevity - QE - Extend to the visible range - Rad-hardness up to 10^{11} n_{eq}/cm^2	WG3 (3.1C), WG6, WG7 (7.1-4)	1.1	- Study hydrogenated nanodiamonds - Study diamond-like carbon (DLC)	- Demonstrate the performance of nanodiamond-powder photocathodes in terms of their chemical reactivity and ageing - Provide a detailed characterization of QE of new photocathode materials, e.g. DLC	INFN-TS, CERN, HIP, IRFU/CEA, NISER Bhubaneswar, U Coimbra, LMU, U Aveiro, RBI, Wigner
T2	IBF suppression, discharge protection	- IBF reduction down to 10^{-4} and below - Stable, high gain operation up to 10^5-10^6 - Operation in magnetic field	WG4, WG7 (7.1,5)	1.2	- Multi-Micromegas detectors - Zero IBF detectors - New structures (Cobra, M-THGEM,) and coating materials (Mo) - Grids: bi-polar grids, gating GEM	- Demonstrate a small-area new structure or stack of structures providing stable operation at high gains and low IBF performance	USTC, INFN-TS, INFN-PD, INFN-PV, TUM, WIS, U Bonn, HIP, IRFU/CEA, NISER Bhubaneswar, CERN, MSU, SBU, JLab, BNL, U Coimbra, IPPLM, U Aveiro, RBI
T3	Gas studies	- Develop eco-friendly gas radiators and, in particular, explore alternatives to CF_4	WG3 (3.2A), WG4, WG7 (7.2,4)	1.1, 1.3	- Identification of eco-friendly gas mixtures free from greenhouse gases - Alternatives to CF_4 for optical readout		CERN, NISER Bhubaneswar, HUJI, GSSI, INFN-PD, INFN-TS, AGH-Krakow, IPPLM, USC/IGFAE, U Aveiro
T4	FEE	- Stability at high input capacitance - Low noise - Large dynamic range	WG5	1.2		- Present an ASIC concept/prototype	IFUSP, NISER Bhubaneswar, INFN-PD, INFN-TS, AGH-Krakow, IPPLM, U Manchester, MSU, SBU, JLab, DIPC
T5	Enhance mechanics	- High-pressure operation - Improve gas tightness	WG6	1.3			NISER Bhubaneswar, HUJI, GSSI, USC/IGFAE, CERN, MSU, JLab, DIPC, IPPLM, RBI
T6	Precision measurements	- Time resolution ≤ 100 ps - Spatial resolution ≤ 1 mm	WG7.2		- MPGD: PICOSEC		CERN, IPPLM

WP7: Timing detectors

(PID AND TRIGGER)

Challenges/tasks

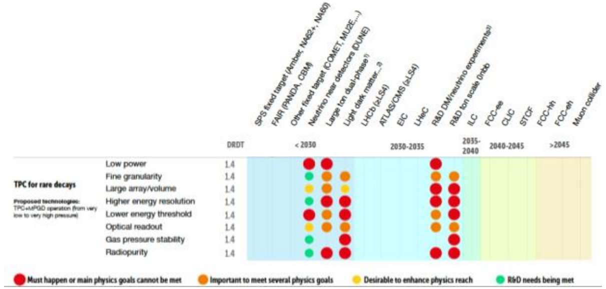
- Uniform rate capability, time resolution, and efficiency over large detector area
- New material for high rate (low res., rad.hard.): uniform gas distribution, spacer material, spacer geometry, thinner structures: mechanical stability and uniformity
- Eco-gas mixture, Gas recuperation systems
- Electronics: Low noise, fast rise time, sensitive to small charge



#	Task	Performance Goal	DRD1 WGs	ECFA DRDT	Comments	Deliv. next 3y	Interested Institutes
T1	Optimize the amplification technology	- Uniformity over m^2 (time resolution, rate capability, efficiency)	WG1, WG6, WG7 (7.1-2,4)	1.1-1.3	- PICOSEC - Position-sensitive timing RPC - Ultra high-rate timing RPC development - DLC-based timing RPC - GaAs timing RPC – Resistive Cylindrical Chamber RCC	- Provide a large-area, multi-channel prototype of an MPGD-based timing detector	CERN, IRFU/CEA, U Sofia, USTC, HIP, GANIL, IP2I, MPP, U Heidelberg, NCSR Demokritos, INFN-BA, INFN-PD, INFN-PV, LIP-Coimbra, U Bursa, MSU, SBU, JLab, U Hamburg, RBI, U Tsinghua, INFN-RM2
T2	Enhance timing	- Time resolution < 20 ps up to 30 kHz/cm^2	WG3 (3.2A, 3.2D), WG4, WG7 (7.2)	1.1	MPGD:PICOSEC	- Present large area MPGD timing detector capabilities in beam	CERN, IRFU/CEA, USTC, HIP, GANIL, IP2I, MPP, NCSR Demokritos, INFN-PD, INFN-PV, U Bursa, SBU, JLab, MSU, UW–Madison, U Hamburg, RBI
T3	Enhance rate capability	- Time resolution < 50 ps up to 100-150 kHz/cm^2	WG3, WG4, WG7 (7.2)	1.3	RPC: - Gap thickness - Number of gaps - Thin, low-R glass - Single cell layout - GaAs timing RPC - Resistive Cylindrical Chamber RCC PICOSEC: use at high rate	- Provide a prototype for >100 kHz/cm^2 rate capability	CERN, IRFU/CEA, U Sofia, USTC, HIP, GANIL, IP2I, MPP, U Heidelberg, NCSR Demokritos, INFN-BA, INFN-PD, INFN-PV, LIP-Coimbra, U Bursa, U Manchester, MSU, SBU, JLab, CIEMAT, VUB and UGent, Istinye U, INFN-RM2
T4	Material studies	- Rad-hardness - Longevity	WG3, WG7 (7.3,4)	1.1-1.3	- Low-resistivity glass - Spacers - Photocathodes - Photoconverters - GaAs - HPL or phenolic glass		INFN-PV, CERN, USTC, RBI, MPP, U Heidelberg, U Manchester, RBI, INFN-RM2
T5	Low-noise FEE	- High input capacitance - Large dynamic range - Fast rise time - Sensitivity to small charges - Low noise	WG5	1.2		- ASIC design - Full readout-chain for multichannel readout solutions for timing ≈10 ps (discrete and ASICs)	USTC, IP2I, IRFU/CEA, GSI, MPP, INFN-PD, INFN-PV, LIP-Coimbra, CERN, U Manchester, MSU, SBU, JLab, INFN-TO, RBI, U Tsinghua, INFN-RM2
T6	Space charge effects, IBF and stability		WG4, WG7 (7.1-2,5)		- Simulations - High gain operation - Synergy with trackers and TPCs		CERN, GSI, U Aveiro, U Tsinghua
T7	Gas studies	- Eco-friendly mixtures - Recuperation - Ageing - CO_2 based mixture with geometrical quenching	WG3 (3.2A, 3.2B, 3.2C), WG7 (7.2-4)	1.3	- Low-GWP solutions for saturated-avalanche operation	- Gas mixtures for MPGD(PICOSEC) based timing detectors (replacement of Ne, CF_4, C_2H_6)	U Sofia, USTC, HIP, GANIL, IP2I, MPP, U Heidelberg, INFN-BA, INFN-PV, LIP-Coimbra, CERN, MSU, SBU, JLab, LMU, U Aveiro, INFN-RM2

WP8: TPCs as reaction and decay chambers

(RARE EVENTS, NEUTRINO PHYSICS, NUCLEAR PHYSICS)

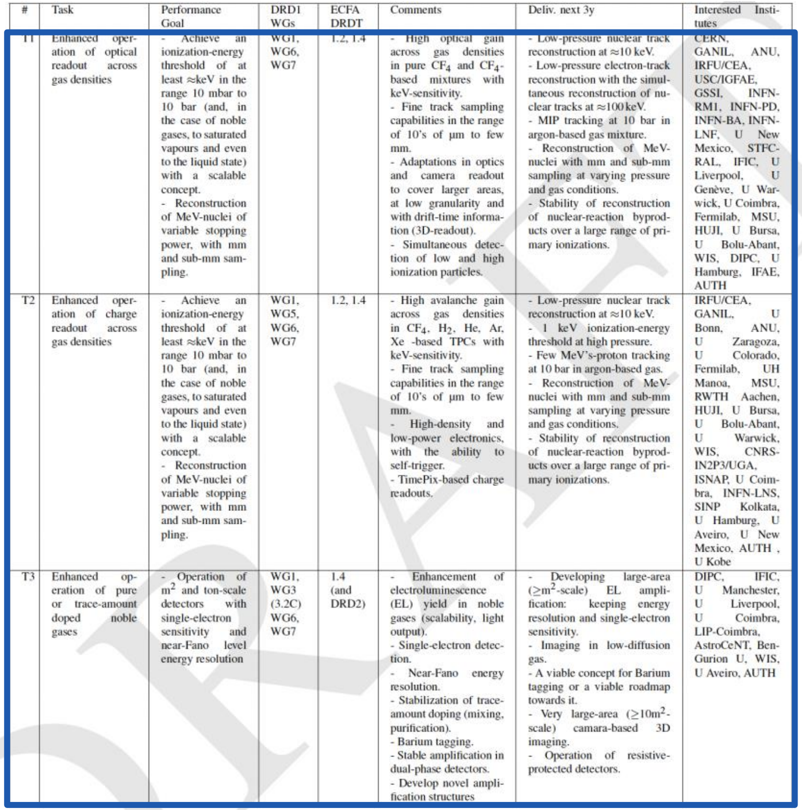


			< 2030						2030-2035						2035-2040	2040-2045			>2045		
		DRDT	SPS fixed target (Amber, NA62+, NA60)	FAIR (PANDA, CBM)	Other fixed target (COMET, MU2E...)	Neutrino near detectors (DUNE)	Large ton dual-phase $^{1)}$	Light dark matter... $^{2)}$	LHCb (≥LS4)	ATLAS/CMS (≥LS4)	EIC	LHeC	R&D DM/neutrino experiments $^{3)}$	R&D ton scale 0νbb	ILC	FCC-ee	CLIC	STCF	FCC-hh	FCC-eh	Muon collider
TPC for rare decays **Proposed technologies:** TPC+MPGD operation (from very low to very high pressure)	Low power	1.4				🔴	🔴						🔴								
	Fine granularity	1.4				🟢	🟠	🟠					🟠	🟠							
	Large array/volume	1.4				🟡	🟠	🟡					🔴	🔴							
	Higher energy resolution	1.4				🟢	🔴	🔴					🔴	🔴							
	Lower energy threshold	1.4				🔴	🟠	🔴					🟠	🔴							
	Optical readout	1.4				🟡	🟠	🟠					🟠	🟠							
	Gas pressure stability	1.4				🟢		🔴						🔴							
	Radiopurity	1.4				🟢	🔴	🔴					🔴	🔴							

🔴 Must happen or main physics goals cannot be met 🟠 Important to meet several physics goals 🟡 Desirable to enhance physics reach 🟢 R&D needs being met

Challenges/tasks

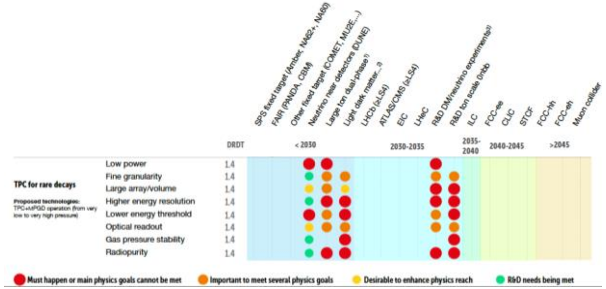
- Reconstruct low-energy nuclear tracks (down to 10 keV energy-scale) with high granularity and close to the thermal diffusion limit.
- Low energy threshold (keV or less) far from atmospheric pressure (10mbar-20bar).
- Achieving high and uniform amplification in nearly pure or weakly-doped noble gases
- Increasing optical throughput (primary and secondary)
- Developing more suitably scintillating and/or eco-friendly gas mixtures as well as recuperation systems;
- Enhancing the radiopurity of the amplification structure and of the TPC as a whole



#	Task	Performance Goal	DRD1 WGs	ECFA DRDT	Comments	Deliv. next 3y	Interested Institutes
T1	Enhanced operation of optical readout across gas densities	- Achieve an ionization-energy threshold of at least ≈keV in the range 10 mbar to 10 bar (and, in the case of noble gases, to saturated vapours and even to the liquid state) with a scalable concept. - Reconstruction of MeV-nuclei of variable stopping power, with mm and sub-mm sampling.	WG1, WG6, WG7	1.2, 1.4	- High optical gain across gas densities in pure CF_4 and CF_4-based mixtures with keV-sensitivity. - Fine track sampling capabilities in the range of 10's of μm to few mm. - Adaptations in optics and camera readout to cover larger areas, at low granularity and with drift-time information (3D-readout). - Simultaneous detection of low and high ionization particles.	- Low-pressure nuclear track reconstruction at ≈10 keV. - Low-pressure electron-track reconstruction with the simultaneous reconstruction of nuclear tracks at ≈100 keV. - MIP tracking at 10 bar in argon-based gas mixture. - Reconstruction of MeV-nuclei with mm and sub-mm sampling at varying pressure and gas conditions. - Stability of reconstruction of nuclear-reaction byproducts over a large range of primary ionizations.	CERN, GANIL, ANU, IRFU/CEA, USC/IGFAE, GSSI, INFN-RM1, INFN-PD, INFN-BA, INFN-LNF, U New Mexico, STFC-RAL, IFIC, U Liverpool, U Genève, U Warwick, U Coimbra, Fermilab, MSU, HUJI, U Bursa, U Bolu-Abant, WIS, DIPC, U Hamburg, IFAE, AUTH
T2	Enhanced operation of charge readout across gas densities	- Achieve an ionization-energy threshold of at least ≈keV in the range 10 mbar to 10 bar (and, in the case of noble gases, to saturated vapours and even to the liquid state) with a scalable concept. - Reconstruction of MeV-nuclei of variable stopping power, with mm and sub-mm sampling.	WG1, WG5, WG6, WG7	1.2, 1.4	- High avalanche gain across gas densities in CF_4, H_2, He, Ar, Xe -based TPCs with keV-sensitivity. - Fine track sampling capabilities in the range of 10's of μm to few mm. - High-density and low-power electronics, with the ability to self-trigger. - TimePix-based charge readouts.	- Low-pressure nuclear track reconstruction at ≈10 keV. - 1 keV ionization-energy threshold at high pressure. - Few MeV's-proton tracking at 10 bar in argon-based gas. - Reconstruction of MeV-nuclei with mm and sub-mm sampling at varying pressure and gas conditions. - Stability of reconstruction of nuclear-reaction byproducts over a large range of primary ionizations.	IRFU/CEA, GANIL, U Bonn, ANU, U Zaragoza, U Colorado, Fermilab, UH Manoa, MSU, RWTH Aachen, HUJI, U Bursa, U Bolu-Abant, U Warwick, WIS, CNRS-IN2P3/UGA, ISNAP, U Coimbra, INFN-LNS, SINP Kolkata, U Hamburg, U Aveiro, U New Mexico, AUTH , U Kobe
T3	Enhanced operation of pure or trace-amount doped noble gases	- Operation of m^2 and ton-scale detectors with single-electron sensitivity and near-Fano level energy resolution	WG1, WG3 (3.2C) WG6, WG7	1.4 (and DRD2)	- Enhancement of electroluminescence (EL) yield in noble gases (scalability, light output). - Single-electron detection. - Near-Fano energy resolution. - Stabilization of trace-amount doping (mixing, purification). - Barium tagging. - Stable amplification in dual-phase detectors. - Develop novel amplification structures	- Developing large-area ($\geq m^2$-scale) EL amplification: keeping energy resolution and single-electron sensitivity. - Imaging in low-diffusion gas. - A viable concept for Barium tagging or a viable roadmap towards it. - Very large-area ($\geq 10m^2$-scale) camara-based 3D imaging. - Operation of resistive-protected detectors.	DIPC, IFIC, U Manchester, U Liverpool, U Coimbra, LIP-Coimbra, AstroCeNT, Ben-Gurion U, WIS, U Aveiro, AUTH

WP8: TPCs as reaction and decay chambers

(RARE EVENTS, NEUTRINO PHYSICS, NUCLEAR PHYSICS)

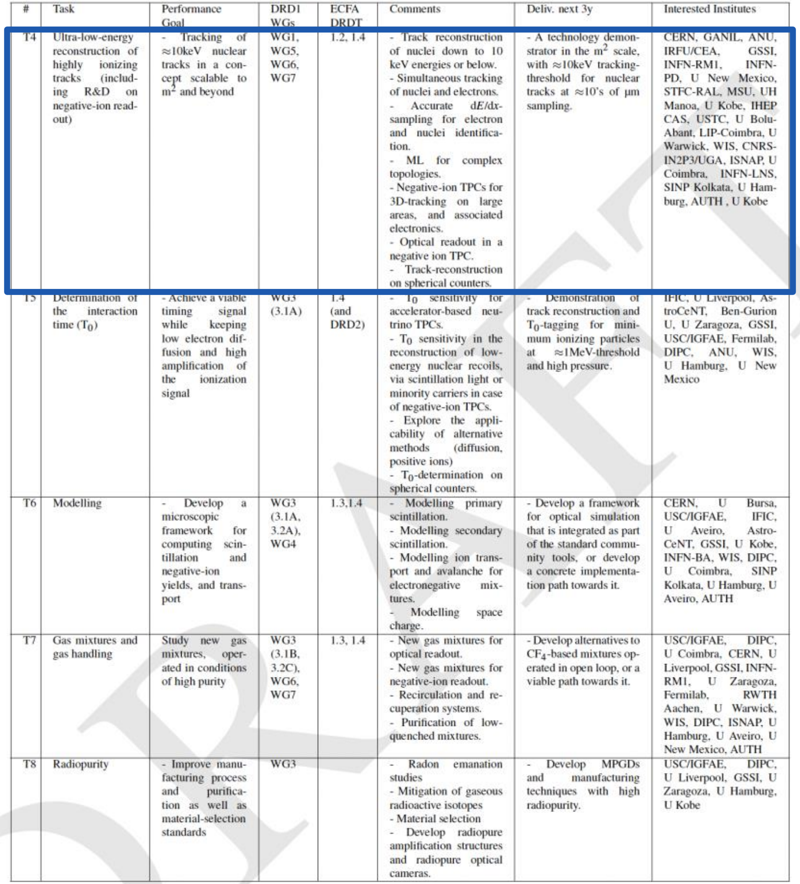


		DRDT	< 2030						2030-2035						2035-2040	2040-2045			>2045		
			SPS fixed target (Amber, NA62+, NA60)	FAIR (PANDA, CBM)	Other fixed target (COMET, MU2E,...)	Neutrino near detectors (DUNE)	Large ton dual-phase 1)	Light dark matter... 2)	LHCb (≥LS4)	ATLAS/CMS (≥LS4)	EIC	LHeC	R&D DM/neutrino experiments 3)	R&D ton scale 0nbb	ILC	FCC-ee	CLIC	STCF	FCC-hh	FCC-eh	Muon collider
TPC for rare decays **Proposed technologies:** TPC+MPGD operation (from very low to very high pressure)	Low power	1.4				🔴	🔴						🔴								
	Fine granularity	1.4				🟢	🟠	🟠					🟠	🟠							
	Large array/volume	1.4				🟡	🟠	🟡					🔴	🔴							
	Higher energy resolution	1.4				🟢	🔴	🔴					🔴	🔴							
	Lower energy threshold	1.4				🔴	🟠	🔴					🟠	🔴							
	Optical readout	1.4				🟡	🟠	🟠					🟠	🟠							
	Gas pressure stability	1.4				🟢		🔴						🔴							
	Radiopurity	1.4				🟢	🔴	🔴					🔴	🔴							

🔴 Must happen or main physics goals cannot be met 🟠 Important to meet several physics goals 🟡 Desirable to enhance physics reach 🟢 R&D needs being met

Challenges/tasks

- Reconstruct low-energy nuclear tracks (down to 10 keV energy-scale) with high granularity and close to the thermal diffusion limit.
- Low energy threshold (keV or less) far from atmospheric pressure (10mbar-20bar).
- Achieving high and uniform amplification in nearly pure or weakly-doped noble gases
- Increasing optical throughput (primary and secondary)
- Developing more suitably scintillating and/or eco-friendly gas mixtures as well as recuperation systems;
- Enhancing the radiopurity of the amplification structure and of the TPC as a whole



#	Task	Performance Goal	DRD1 WGs	ECFA DRDT	Comments	Deliv. next 3y	Interested Institutes
T4	Ultra-low-energy reconstruction of highly ionizing tracks (including R&D on negative-ion readout)	- Tracking of $\approx$10keV nuclear tracks in a concept scalable to m^2 and beyond	WG1, WG5, WG6, WG7	1.2, 1.4	- Track reconstruction of nuclei down to 10 keV energies or below. - Simultaneous tracking of nuclei and electrons. - Accurate dE/dx-sampling for electron and nuclei identification. - ML for complex topologies. - Negative-ion TPCs for 3D-tracking on large areas, and associated electronics. - Optical readout in a negative ion TPC. - Track-reconstruction on spherical counters.	- A technology demonstrator in the m^2 scale, with $\approx$10keV tracking-threshold for nuclear tracks at $\approx$10's of μm sampling.	CERN, GANIL, ANU, IRFU/CEA, GSSI, INFN-RM1, INFN-PD, U New Mexico, STFC-RAL, MSU, UH Manoa, U Kobe, IHEP CAS, USTC, U Bolu-Abant, LIP-Coimbra, U Warwick, WIS, CNRS-IN2P3/UGA, ISNAP, U Coimbra, INFN-LNS, SINP Kolkata, U Hamburg, AUTH , U Kobe
T5	Determination of the interaction time (T_0)	- Achieve a viable timing signal while keeping low electron diffusion and high amplification of the ionization signal	WG3 (3.1A)	1.4 (and DRD2)	- T_0 sensitivity for accelerator-based neutrino TPCs. - T_0 sensitivity in the reconstruction of low-energy nuclear recoils, via scintillation light or minority carriers in case of negative-ion TPCs. - Explore the applicability of alternative methods (diffusion, positive ions) - T_0-determination on spherical counters.	- Demonstration of track reconstruction and T_0-tagging for minimum ionizing particles at $\approx$1MeV-threshold and high pressure.	IFIC, U Liverpool, AstroCeNT, Ben-Gurion U, U Zaragoza, GSSI, USC/IGFAE, Fermilab, DIPC, ANU, WIS, U Hamburg, U New Mexico
T6	Modelling	- Develop a microscopic framework for computing scintillation and negative-ion yields, and transport	WG3 (3.1A, 3.2A), WG4	1.3,1.4	- Modelling primary scintillation. - Modelling secondary scintillation. - Modelling ion transport and avalanche for electronegative mixtures. - Modelling space charge.	- Develop a framework for optical simulation that is integrated as part of the standard community tools, or develop a concrete implementation path towards it.	CERN, U Bursa, USC/IGFAE, IFIC, U Aveiro, AstroCeNT, GSSI, U Kobe, INFN-BA, WIS, DIPC, U Coimbra, SINP Kolkata, U Hamburg, U Aveiro, AUTH
T7	Gas mixtures and gas handling	Study new gas mixtures, operated in conditions of high purity	WG3 (3.1B, 3.2C), WG6, WG7	1.3, 1.4	- New gas mixtures for optical readout. - New gas mixtures for negative-ion readout. - Recirculation and recuperation systems. - Purification of low-quenched mixtures.	- Develop alternatives to CF_4-based mixtures operated in open loop, or a viable path towards it.	USC/IGFAE, DIPC, U Coimbra, CERN, U Liverpool, GSSI, INFN-RM1, U Zaragoza, Fermilab, RWTH Aachen, U Warwick, WIS, DIPC, ISNAP, U Hamburg, U Aveiro, U New Mexico, AUTH
T8	Radiopurity	- Improve manufacturing process and purification as well as material-selection standards	WG3		- Radon emanation studies - Mitigation of gaseous radioactive isotopes - Material selection - Develop radiopure amplification structures and radiopure optical cameras.	- Develop MPGDs and manufacturing techniques with high radiopurity.	USC/IGFAE, DIPC, U Liverpool, GSSI, U Zaragoza, U Hamburg, U Kobe

(WP9: Beyond HEP)

- No WP9 in the first proposal
- Community feedback: clear need of Beuyond HEP WP definition
- To be discussed on Thursday

- We can identify different tasks:
  - muography and large area applications;
  - dosimetry/beam monitoring and medical imaging applications (PET, CT, X-ray, SPECT, Gamma cameras, or X-ray fluorescence imaging);
  - fast/thermal neutron imaging (MPGD-based readout with solid converter for tomography and nuclear waste monitoring;
  - X-ray polarimetry and space applications;

Next steps

- WP Coordinators will contact ALL institutes which shared their interest in given WP topics in the survey and/or community feedback

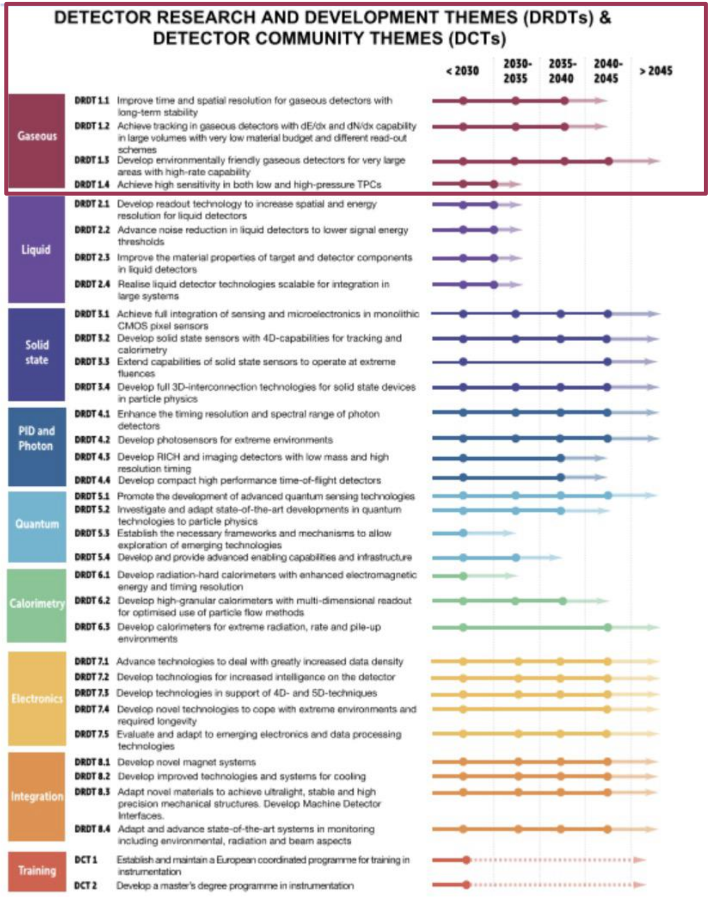
- Institutes can still be added/removed from the individual WP and their tasks
  - It is **not required** to be involved in a WP to be a member of DRD1
  - It is **required** to be a member of DRD1 to contribute to a WP

- ”Extended WP tables” will be created together with institutes which declare their contribution to specific WPs
  - “WP projects” with well defined tasks will cluster institutes interested in common goals;
  - Final DRD1-proposal WP tables (following current scheme) will be a compilation of such “WP projects”
  - The institutes intrtested to contribute to a given WP need to provide FTE and non-FTE resources in the extended WP tables
  - We differentiate between “existing” and “requested” resources.
  - WP can help in acquiring strategic funding, however, it is not mandatory for an institute to apply for extra funding. One can contribute with the exiting resources only

- WP can be created at any time in the future

BACKUP SLIDES

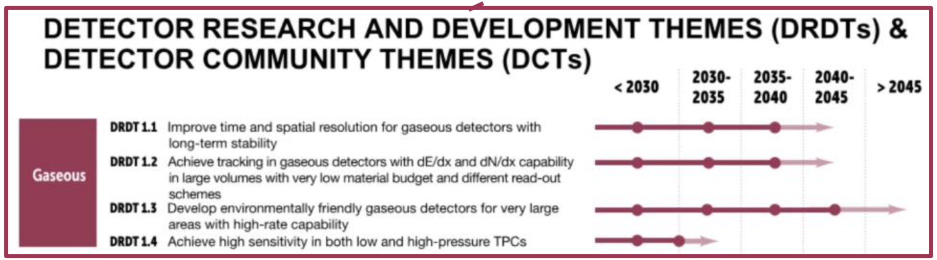
DRD Themes



DETECTOR RESEARCH AND DEVELOPMENT THEMES (DRDTs) & DETECTOR COMMUNITY THEMES (DCTs)

< 2030 | 2030-2035 | 2035-2040 | 2040-2045 | > 2045

Gaseous	DRDT 1.1	Improve time and spatial resolution for gaseous detectors with long-term stability
	DRDT 1.2	Achieve tracking in gaseous detectors with dE/dx and dN/dx capability in large volumes with very low material budget and different read-out schemes
	DRDT 1.3	Develop environmentally friendly gaseous detectors for very large areas with high-rate capability
	DRDT 1.4	Achieve high sensitivity in both low and high-pressure TPCs
Liquid	DRDT 2.1	Develop readout technology to increase spatial and energy resolution for liquid detectors
	DRDT 2.2	Advance noise reduction in liquid detectors to lower signal energy thresholds
	DRDT 2.3	Improve the material properties of target and detector components in liquid detectors
	DRDT 2.4	Realise liquid detector technologies scalable for integration in large systems
Solid state	DRDT 3.1	Achieve full integration of sensing and microelectronics in monolithic CMOS pixel sensors
	DRDT 3.2	Develop solid state sensors with 4D-capabilities for tracking and calorimetry
	DRDT 3.3	Extend capabilities of solid state sensors to operate at extreme fluences
	DRDT 3.4	Develop full 3D-interconnection technologies for solid state devices in particle physics
PID and Photon	DRDT 4.1	Enhance the timing resolution and spectral range of photon detectors
	DRDT 4.2	Develop photosensors for extreme environments
	DRDT 4.3	Develop RICH and imaging detectors with low mass and high resolution timing
	DRDT 4.4	Develop compact high performance time-of-flight detectors
Quantum	DRDT 5.1	Promote the development of advanced quantum sensing technologies
	DRDT 5.2	Investigate and adapt state-of-the-art developments in quantum technologies to particle physics
	DRDT 5.3	Establish the necessary frameworks and mechanisms to allow exploration of emerging technologies
	DRDT 5.4	Develop and provide advanced enabling capabilities and infrastructure
Calorimetry	DRDT 6.1	Develop radiation-hard calorimeters with enhanced electromagnetic energy and timing resolution
	DRDT 6.2	Develop high-granular calorimeters with multi-dimensional readout for optimised use of particle flow methods
	DRDT 6.3	Develop calorimeters for extreme radiation, rate and pile-up environments
Electronics	DRDT 7.1	Advance technologies to deal with greatly increased data density
	DRDT 7.2	Develop technologies for increased intelligence on the detector
	DRDT 7.3	Develop technologies in support of 4D- and 5D-techniques
	DRDT 7.4	Develop novel technologies to cope with extreme environments and required longevity
	DRDT 7.5	Evaluate and adapt to emerging electronics and data processing technologies
Integration	DRDT 8.1	Develop novel magnet systems
	DRDT 8.2	Develop improved technologies and systems for cooling
	DRDT 8.3	Adapt novel materials to achieve ultralight, stable and high precision mechanical structures. Develop Machine Detector Interfaces.
	DRDT 8.4	Adapt and advance state-of-the-art systems in monitoring including environmental, radiation and beam aspects
Training	DCT 1	Establish and maintain a European coordinated programme for training in instrumentation
	DCT 2	Develop a master's degree programme in instrumentation



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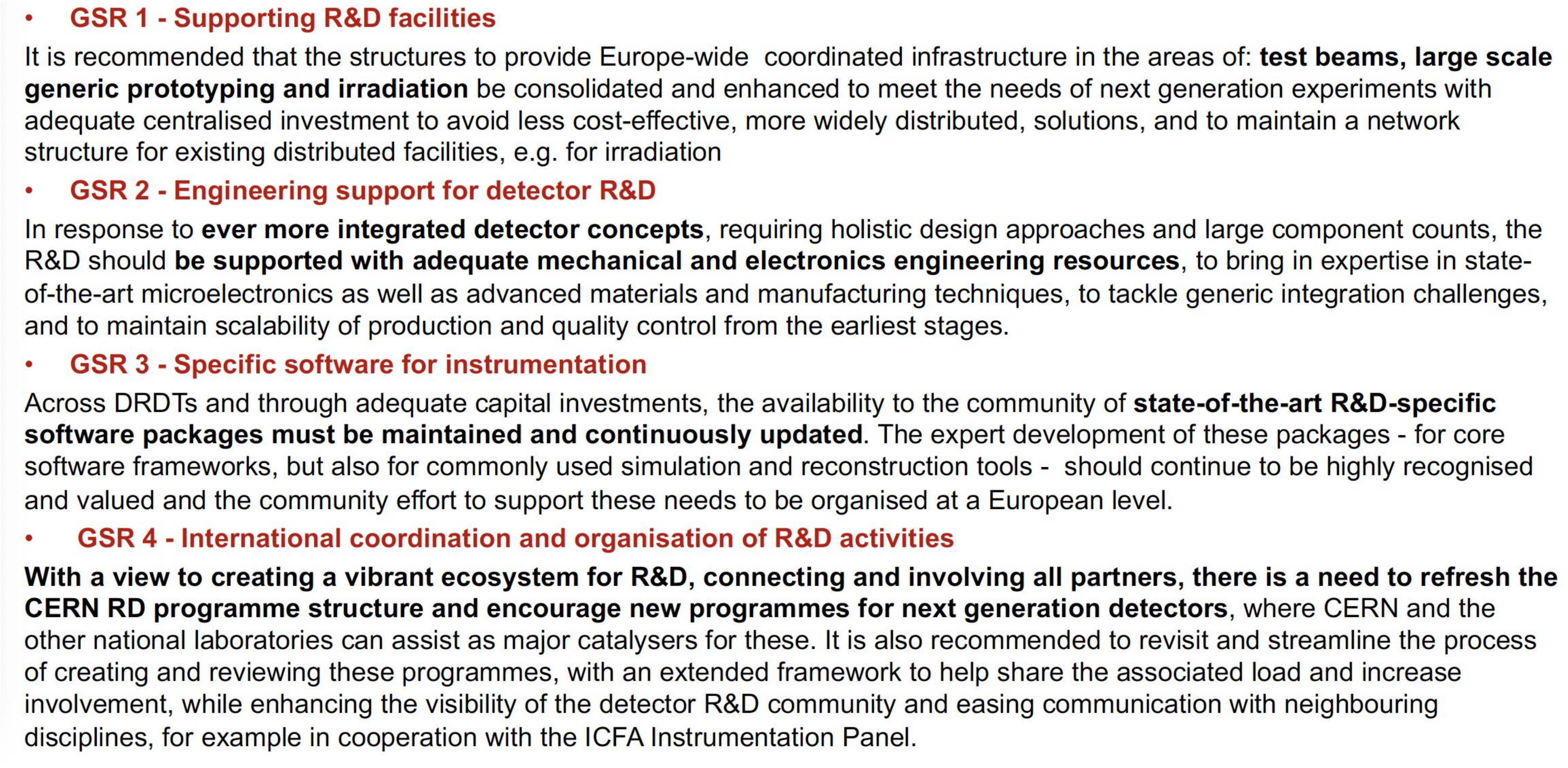
General Strategic Recommendations



- **GSR 1 - Supporting R&D facilities**

It is recommended that the structures to provide Europe-wide coordinated infrastructure in the areas of: **test beams, large scale generic prototyping and irradiation** be consolidated and enhanced to meet the needs of next generation experiments with adequate centralised investment to avoid less cost-effective, more widely distributed, solutions, and to maintain a network structure for existing distributed facilities, e.g. for irradiation

- **GSR 2 - Engineering support for detector R&D**

In response to **ever more integrated detector concepts**, requiring holistic design approaches and large component counts, the R&D should **be supported with adequate mechanical and electronics engineering resources**, to bring in expertise in state-of-the-art microelectronics as well as advanced materials and manufacturing techniques, to tackle generic integration challenges, and to maintain scalability of production and quality control from the earliest stages.

- **GSR 3 - Specific software for instrumentation**

Across DRDTs and through adequate capital investments, the availability to the community of **state-of-the-art R&D-specific software packages must be maintained and continuously updated**. The expert development of these packages - for core software frameworks, but also for commonly used simulation and reconstruction tools - should continue to be highly recognised and valued and the community effort to support these needs to be organised at a European level.

- **GSR 4 - International coordination and organisation of R&D activities**

With a view to creating a vibrant ecosystem for R&D, connecting and involving all partners, there is a need to refresh the CERN RD programme structure and encourage new programmes for next generation detectors, where CERN and the other national laboratories can assist as major catalysers for these. It is also recommended to revisit and streamline the process of creating and reviewing these programmes, with an extended framework to help share the associated load and increase involvement, while enhancing the visibility of the detector R&D community and easing communication with neighbouring disciplines, for example in cooperation with the ICFA Instrumentation Panel.

General Strategic Recommendations

- **GSR 5 - Distributed R&D activities with centralised facilities**

Establish in the relevant R&D areas a distributed yet connected and supportive tier-ed system for R&D efforts across Europe. Keeping in mind the growing complexity, the specialisation required, the learning curve and the increased cost, consider more focused investment for those themes where leverage can be reached through centralisation at large institutions, while addressing the challenge that distributed resources remain accessible to researchers across Europe and through them also be available to help provide enhanced training opportunities.

- **GSR 6 - Establish long-term strategic funding programmes**

Establish, additional to short-term funding programmes for the early proof of principle phase of R&D, also **long-term strategic funding programmes to sustain both research and development of the multi-decade DRDTs** in order for the technology to mature and to be able to deliver the experimental requirements. Beyond capital investments of single funding agencies, international collaboration and support at the EU level should be established. In general, the cost for R&D has increased, which further strengthens the vital need to **make concerted investments**.

- **GSR 7 – “Blue-sky” R&D**

It is essential that adequate resources be provided to support more speculative R&D which can be riskier in terms of immediate benefits but can bring significant and potentially transformational returns if successful both to particle physics: unlocking new physics may only be possible by unlocking novel technologies in instrumentation, and to society. Innovative instrumentation research is one of the defining characteristics of the field of particle physics. **“Blue-sky” developments in particle physics have often been of broader application and had immense societal benefit.** Examples include: the development of the World Wide Web, Magnetic Resonance Imaging, Positron Emission Tomography and X-ray imaging for photon science.

General Strategic Recommendations

- **GSR 8 - Attract, nurture, recognise and sustain the careers of R&D experts**

Innovation in instrumentation is essential to make progress in particle physics, and **R&D experts are essential for innovation**. It is recommended that ECFA, with the involvement and support of its Detector R&D Panel, continues the **study of recognition with a view to consolidate the route to an adequate number of positions with a sustained career in instrumentation R&D** to realise the strategic aspirations expressed in the EPPSU. It is suggested that **ECFA should explore mechanisms to develop concrete proposals in this area and to find mechanisms to follow up on these in terms of their implementation**. Consideration needs to be given to creating sufficiently attractive remuneration packages to retain those with key skills which typically command much higher salaries outside academic research. It should be emphasised that, in parallel, society benefits from the training particle physics provides because the knowledge and skills acquired are in high demand by industries in high-technology economies.

- **GSR 9 - Industrial partnerships**

It is recommended to **identify promising areas for close collaboration between academic and industrial partners**, to create international frameworks for exchange on academic and industrial trends, drivers and needs, and to **establish strategic and resources-loaded cooperation schemes on a European scale to intensify the collaboration with industry**, in particular for developments in solid state sensors and micro-electronics.

- **GSR 10 – Open Science**

It is recommended that **the concept of Open Science be explicitly supported in the context of instrumentation**, taking account of the constraints of commercial confidentiality where these apply due to partnerships with industry. Specifically, for publicly-funded research the default, wherever possible, should be open access publication of results and it is proposed that the Sponsoring Consortium for Open Access Publishing in Particle Physics (SCOAP^3) should explore ensuring similar access is available to instrumentation journals (including for conference proceedings) as to other particle physics publications.